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EVALUATION OF ARCHIMEDEAN SCREW TRACTOR FOR ICE MANAGEMENT

by:

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Submitted to:

TRANSPORTATION DEVELOPMENT CENTRE
ARCTIC PILOT PROJECT
MITSUI ENGINEERING AND SHIPBUILDING CO. LTD.

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17. Resume

Arctec Canada Ltd. a soumis un prototype de véhicule amphibie a vis d'archimède, le AST-002 de concpetion japonaise, à une serie d'essais pour le compte du CDT, du fabricant Mitsuit Engineering and Shipbuilding, et du groupe responsable du projet Pilot de mise en valeur de l'arctique.

Les essais qui ont eu lieu à Thunder Bay (Canada) ont montré que ce véhicule (AVA), se tirait bien d'affaire dans toutes les fonctions qui lui ont été confiées: tracteur, remorqueur, transport de personnes, de marchandises, sauvetage, lutte contre les glaces. Utilisé comme brise-glace en eau douce selon une technique spécialement étudiée, il a obtenu des résultats supérieurs à ce qui avait été prévu.

Le rapport présente les paramètres de conception préconisés pour un véhicule AVA attaché exclusivement au port de Thunder Bay.

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Brise-glace, lutte contre les glaces, tracteur amphibie, Thunder Bay, Véhicule à vis d'Archimède, Maîtrise des glaces	Diffusion restreinte à la demande des participants du secteur privé

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17. Abstract

A japanese built prototype amphibious tractor using archimedean screw rotors, the AST-002, was tested by Arctec Canada Limited for Transportation Development Centre, Arctic Pilot Project and Mitsuit Engineering and Shipbuilding. Testing took place at the Port of Thunder Bay, Canada.

The project showed that the AST performed satisfactorily in all aspects of operation: Tractor, Tugboat, Personnel Vehicle, Cargo Craft, Rescue Craft, Ice Management Vehicle and Icebreaker. Results indicated that fresh water icebreaking capabilities are greater than expected, using specifically developed piloting techniques. Recommendations for an AST, designed specifically for operation at the Port of Thunder Bay, are given.

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Icebreaking, Amphibious Tractor, Thunder Bay, Ice Management, Archimedean Screw Tractors, Ice Control	Not available for general distribution on request of other industrial participants

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1. INTRODUCTION

This study was conducted by ARCTEC CANADA LIMITED on behalf of the Transportation Development Centre of Transport Canada, the Arctic Pilot Project, and Mitsui Engineering and Shipbuilding Co. Ltd. The project was conducted at Thunder Bay, Ontario, during the period from March 11, 1982 through April 7, 1982. The objective of the study was to conduct an evaluation of an amphibious craft, the AST 002, for use as an ice management vehicle, personnel and cargo carrier, rescue craft, and general amphibious Arctic work craft.

As an ice management vehicle, the AST was evaluated for fresh water icebreaking capabilities, for manoeuverability and control in relatively tight areas, and for speed and effectiveness in performing icebreaking tasks. As a personnel, cargo and rescue craft the AST was tested in various travel modes including travel on level ice, in open water, in broken ice (both refrozen and loose), and in icebreaking modes. The few small ridges in the area were successfully crossed. The AST was tested as a working piece of heavy equipment by towing sleds and ice management equipment, by assisting tugboat operations, and by towing an air cushioned vehicle.

Practical ice managment experiments were also conducted, making use of the results of towing tests. Experimental plots were set up and individually treated using the AST and other methods to test various ways of enhancing ice deterioration, employing amphibious heavy machinery.

The Archimedean Screw Tractor (AST) vehicle is based upon the concept of using twin contra-rotating Archimedean Screws for propulsion. This type of screw has been used for centuries for various purposes such as lifting water or moving grain. Development work for use of the screw concept as an Arctic transport propulsion system was begun by the Arctec group for Mitsui in 1972. Computer studies of the concept were followed by model studies of various rotor configurations. A small prototype AST (the AST-001) was built in 1976 by Mitsui. The craft which was brought to Thunder Bay, the AST-002,

is a larger craft with a different transmission system and was built in Japan in 1978. It has been tested in northern Japan and on the Alaskan North Slope. Since it is a prototype vehicle and was designed to be generally tested for a variety of applications, its use for specific test roles required either modifications to the craft or tests designed around the existing craft specifications. For the present study no modifications were made to the AST.

The AST-002 is driven by an air-cooled Mitsui-Duetz V-12 diesel, which operates a hydraulic generator. The hydraulics are connected to two large hydraulic motors on the aft end of the rotor mounts, which are individually controlled (Photo 1). Each rotor rotation is thus separately controlled and may turn in either direction. The craft is propelled forward by contra-rotating the rotors and using the screw threads to pull itself along the suface (Photo 2). Similarly, the rotors are able to propel the craft in water or on snow or mud. The driver controls the rotors with two control levers which operate hydraulic valves (Photo 3). Turning is accomplished by slowing, stopping, or even reversing one rotor while advancing the other.

The AST-002 is able to break ice by applying nearly the total craft weight to the edge of an ice sheet, thereby failing the ice (Photo 4). If the ice is thin enough (approximately 30 cm or less) the AST will fail the ice with its weight without requiring an edge to start. By starting from open water, the AST climbs up the ice edge using the rotor threads and balances briefly on the edge when about 90% out of the water. In this way nearly all of the 11 tonnes of the craft mass is applied to the ice edge.

The AST has a large draw bar pull on ice or snow surfaces - nearly equivalent to its own weight. In water the AST is able to pull about one tonne. It is able to tow much more than its own weight on ice or snow if the load is sled mounted. Reports from some previous tests at Prudhoe Bay indicate that up to 70 tonnes may be pulled under good surface conditions.

A number of AST designs have been proposed for various specific uses, including Arctic barges and oil spill recovery vehicles. The AST concept is

PHOTO 1

GENERAL VIEW OF AST-002

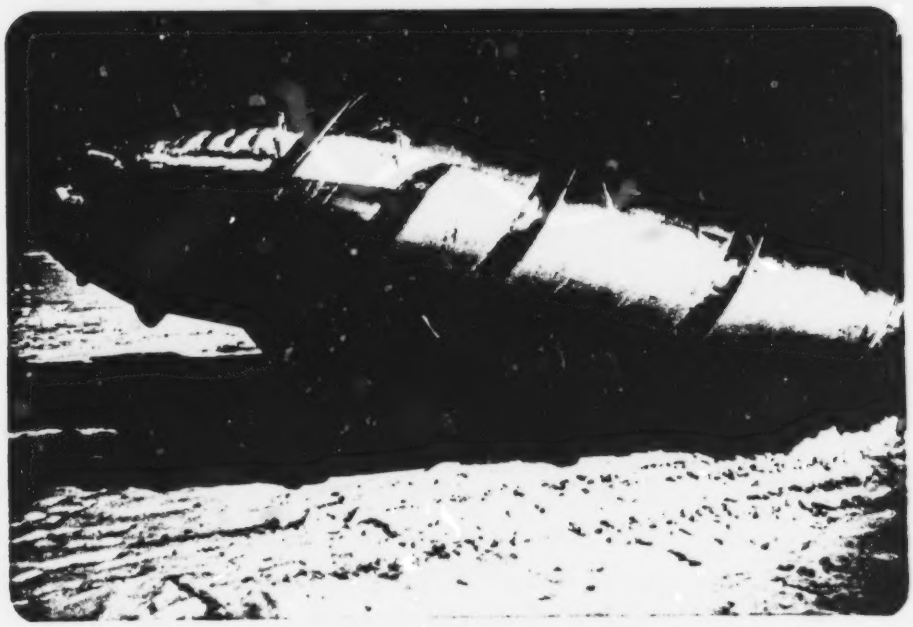


PHOTO 2

AST ROTORS

PHOTO 3

AST DRIVER CONTROLS

PHOTO 4

AST BREAKING ICE

easily modified or redesigned for larger or more powerful craft, or for purposes requiring special accessories or functions.

The Port of Thunder Bay (Figure 1) is located at the head of Lake Superior in Ontario. It is Canada's largest freshwater port and one of the world's largest grain shipping terminals. In addition to grain, many other resources, such as coal, potash and lumber, are shipped from Thunder Bay.

The port (Figure 2) is normally active from the end of March or early April to October. The shipping season is limited in the autumn by deteriorating weather on the Great Lakes, reduced volumes of cargo, and encroaching lake ice. The start of the spring shipping period is exclusively limited by the presence of ice. The date of break-up is variable, depending on weather conditions throughout the winter and in the spring. Sheltered or enclosed areas freeze earliest and melt latest, therefore developing the thickest ice cover. These sheltered areas, which include ship berths, are (with regard to ice cover) the most limiting situations at the port. The Canadian Coast Guard icebreakers are unable to penetrate the ship berths, and local tugboats are effective for clearing ice only after considerable deterioration has occurred. Therefore, an icebreaking craft capable of a high degree of control yet relatively small and maoeuverable is indicated. The AST is such a machine.

Similar ice management problems to those in Thunder Bay are likely to occur in Arctic situations during extended season shipping from ice bound ports. The experiences with the AST at Thunder Bay will contribute to the understanding of dealing with these problems.

A potential problem associated with Arctic shipping is that of possible ship track crossing hazards, as where Inuit hunters in their traditional hunting patterns across a waterway which in the future may carry commercial traffic. Where regular ship tracks occur near traditional travel routes in the Arctic, distribution or danger due to open water has been identified as as a concern. AST type vehicles could be used in situations where such hazards regularly occur.

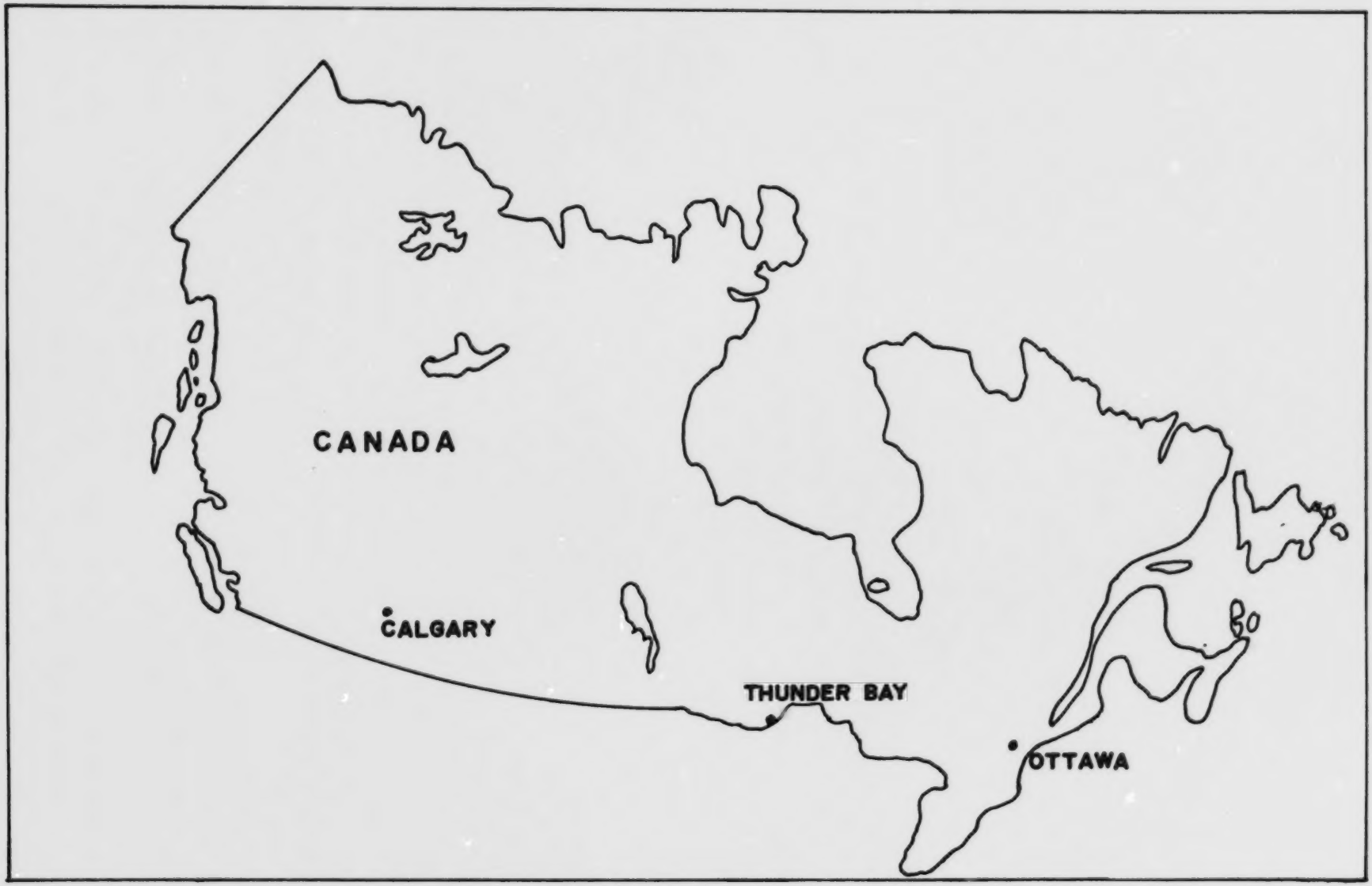
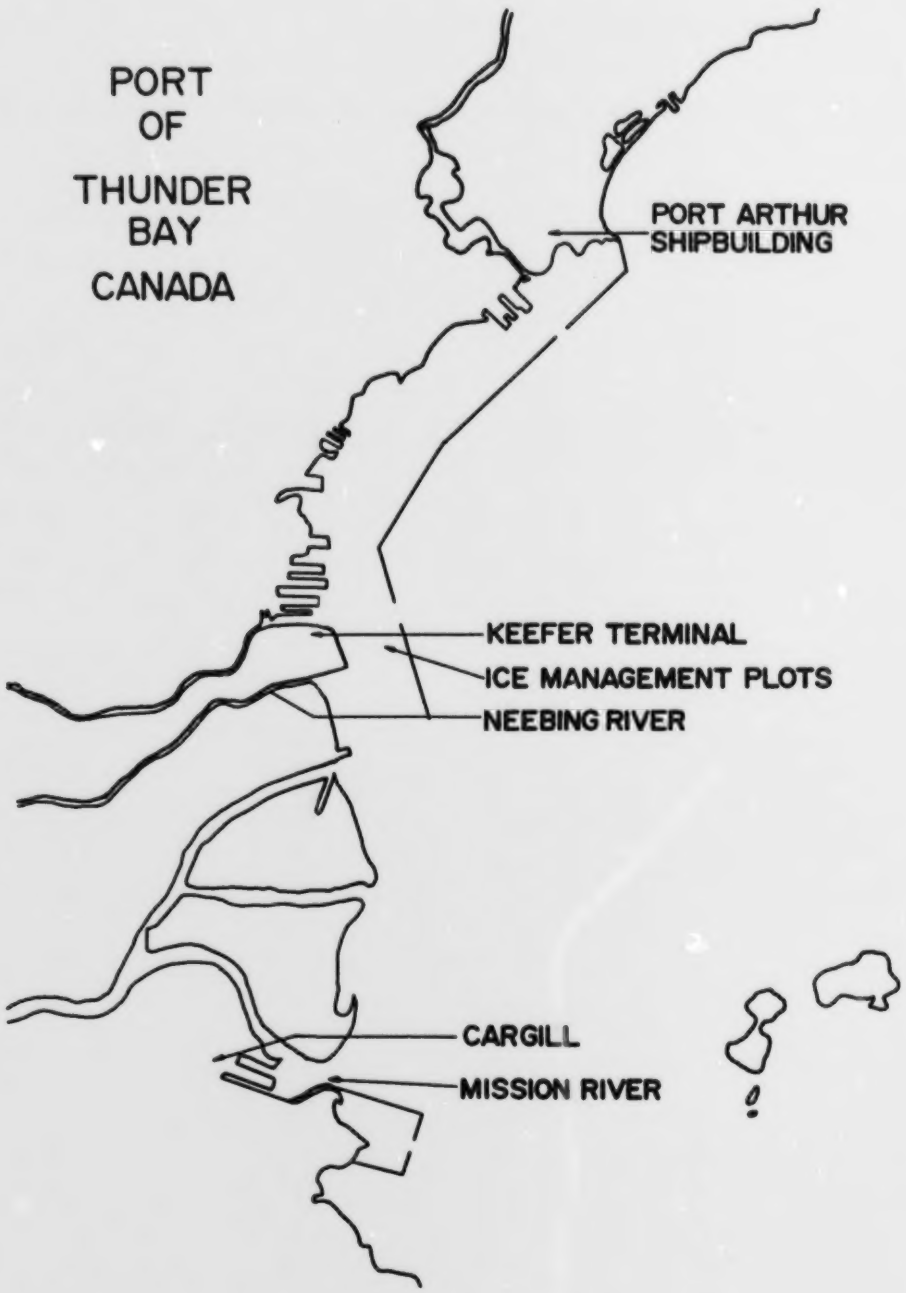


FIGURE I
LOCATION OF THUNDER BAY CANADA

Figure 2


PORT
OF
THUNDER
BAY
CANADA
PORT ARTHUR
SHIPBUILDING
KEEFER TERMINAL
ICE MANAGEMENT PLOTS
NEEBING RIVER
CARGILL
MISSION RIVER

2. METHODS

The test program followed for this study is described below.

The AST was first used to construct sixteen ice management test plots. In this fashion the AST was used like a tractor or a bulldozer: in other words, an amphibious piece of heavy machinery. This portion of the program allowed a great deal of experience to be gained in the control and operation of the craft on level ice and snow.

The test plots included eight different treatments of the frozen lake surface with two sample plots of each treatment. Of the eight different treatments, four different techniques were applied to both snow covered and snowploughed surfaces. The four techniques were dusting, primary scarifying, secondary scarifying, and no treatment: control plots (just ploughed or left snow covered) (Figure 3).

One half of the samples were ploughed free of snow to remove the insulating effect of the snow cover, in the expectation that warm spring air temperatures would more quickly heat the exposed ice, leading to more rapid deterioration. The snow and ice surfaces which were dusted were observed to see if this darker material absorbed sufficient additional incoming radiation to significantly contribute to more rapid ice and snow deterioration. The two levels of scarifying (or surface roughening) which were used were expected to alter the albedo of the surfaces and cause additional absorption of radiation, also leading to an increased rate of ice and snow deterioration. Control plots were set up as comparisons against the treated plots and those which were ploughed only.

The plots which were ploughed had snow removed by the AST pulling a sled-mounted grader blade (Figure 4). A number of passes were required to move the snow off and to the sides of these plots.

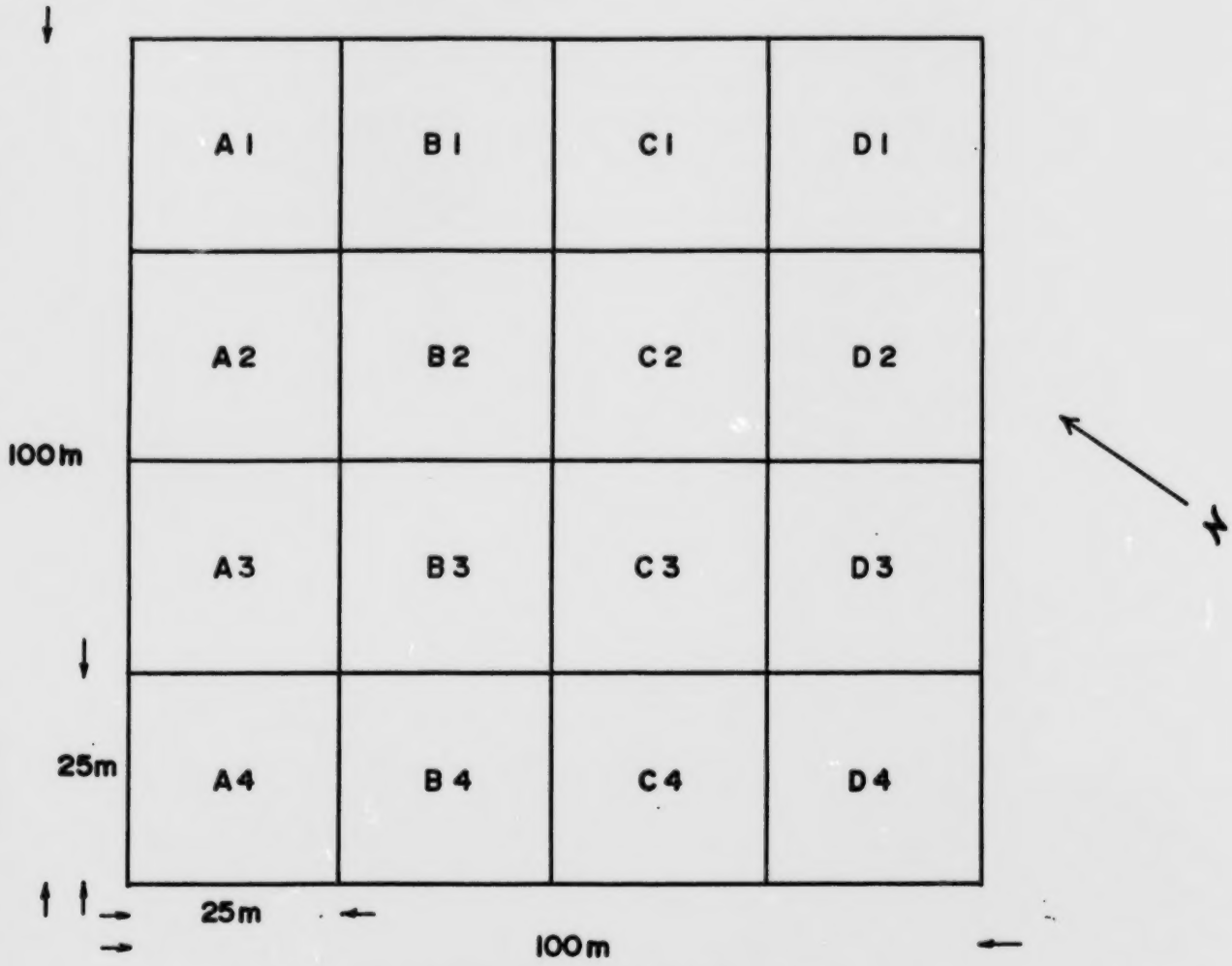
All scarifying was done using a small sled with bottom-mounted teeth of adjustable length, pulled by the AST (Figure 5). The sled was weighted down

With increasing utilization of Arctic and sub-Arctic areas in seasons when travel is difficult due to the presence of ice, the requirements for emergency travel and rescue are increasing. Fast and safe craft which can travel in the varied Arctic marine terrain are required. Vehicles such as the AST provide such possibilities.

The problems outlined above form the basis of the test plan upon which the present study was conducted.

Figure 3

ICE MANAGEMENT TEST PLOTS



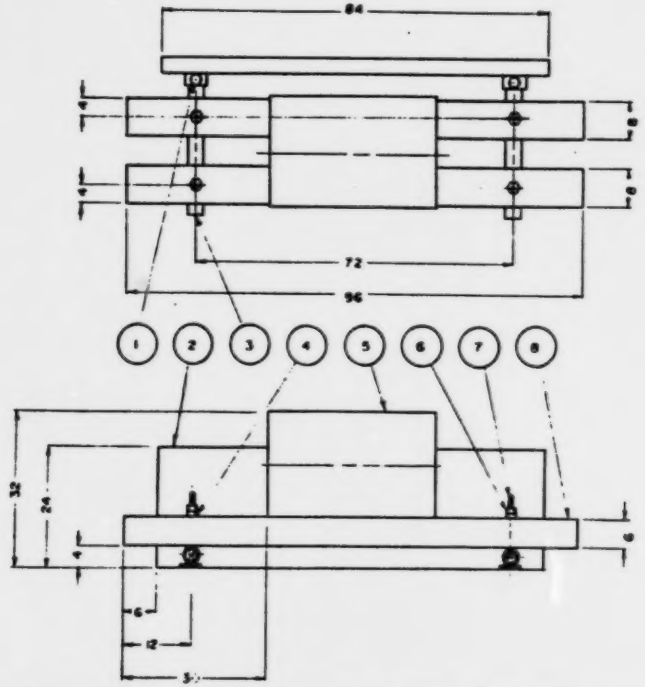
MANAGEMENT TECHNIQUES USED

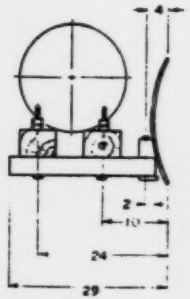
A1	PLOUGHED 2° SCARIFYING	C1	PLOUGHED ONLY
A2	2° SCARIFYING ONLY	C2	CONTROL – NO TECHNIQUES APPLIED
A3	2° SCARIFYING ONLY	C3	CONTROL – NO TECHNIQUES APPLIED
A4	PLOUGHED 2° SCARIFYING	C4	PLOUGHED ONLY
B1	PLOUGHED 1° SCARIFYING	D1	PLOUGHED DUSTED
B2	1° SCARIFYING ONLY	D2	DUSTED ONLY
B3	1° SCARIFYING ONLY	D3	DUSTED ONLY
B4	PLOUGHED 1° SCARIFYING	D4	PLOUGHED, DUSTED

FIGURE: 4 ENGINEERING DRAWING OF PLOUGH

FIGURE 4

NOTE - ALL DIMENSIONS IN INCHES





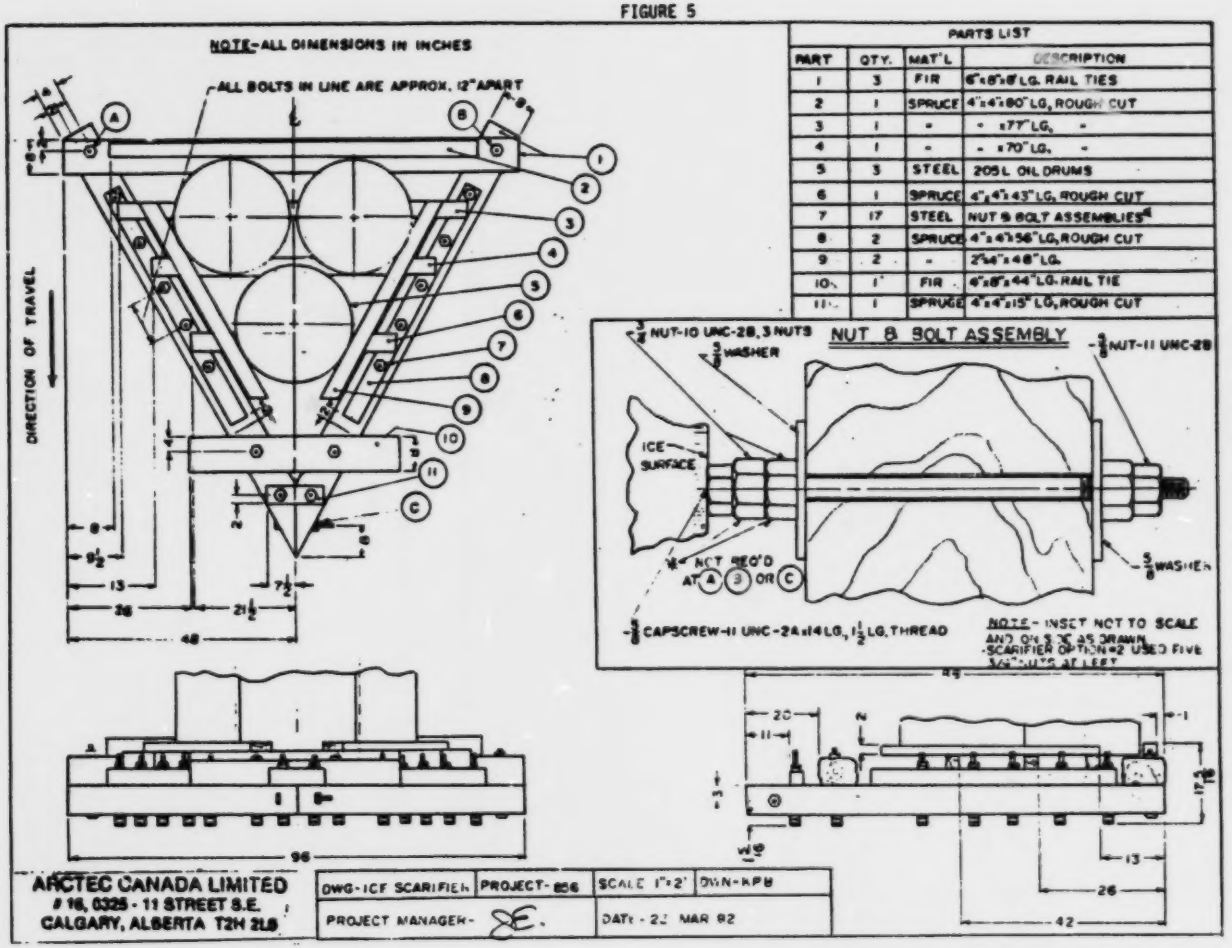
PARTS LIST

PART No.	QTY.	MAT'L	DESCRIPTION
1	2	STEEL	1" DIA. x 5" LG. SHAFT (PLOW BLADE HARDWARE)
2	1	STEEL	'BEAVER' 84" LG. TRUCK PLOW
3	2	STEEL	PIPE - 2 3/4" DIA. x 1/4" THICK x 28" LG. THREE THROUGH HOLES LOCATED IN LINE AT DISTANCES OF 2", 9" AND 23" FROM ONE END. DIAMETERS ARE 1", 11/16" AND 11/16" RESPECTIVELY.
4	4	STEEL	SPACER NUTS - 3/4"-10 UNC-2B
5	1	STEEL	205 L WATER FILLED DRUM
6	4	STEEL	NUTS - 5/8"-11 UNC-2B
7	4	STEEL	14" LG. HEX HEAD BOLTS, THREADS 5/8"-11 UNC-2A x 1 1/2" LG.
8	2	FIR	6" x 8" x 9' LG. RAILWAY TIES

ARCTEC CANADA LIMITED # 16, 6325 - 11 STREET S.E. CALGARY, ALBERTA T2H 2L8	DWG - SNOW PLOW	PROJECT - 854	SCALE - 1"=2'	DWN - KPB
	PROJECT MANAGER -		DATE - 18 APR 92	

FIGURE: 5 ENGINEERING DRAWING OF SCARIFIER

FIGURE 5


NOTE-ALL DIMENSIONS IN INCHES
ALL BOLTS IN LINE ARE APPROX. 12" APART
DIRECTION OF TRAVEL
PARTS LIST
PART | QTY. | MAT'L | DESCRIPTION
1 | 3 | FIR | 6"x8"x8' LG. RAIL TIES
2 | 1 | SPRUCE | 4"x4"x80" LG, ROUGH CUT
3 | 1 | - | - x77" LG, -
4 | 1 | - | - x70" LG, -
5 | 3 | STEEL | 205 L OIL DRUMS
6 | 1 | SPRUCE | 4"x4"x43" LG, ROUGH CUT
7 | 17 | STEEL | NUT & BOLT ASSEMBLIES
8 | 2 | SPRUCE | 4"x4"x56" LG, ROUGH CUT
9 | 2 | - | 2"x4"x48" LG.
10 | 1 | FIR | 6"x8"x44" LG. RAIL TIE
11 | 1 | SPRUCE | 4"x4"x15" LG, ROUGH CUT
NUT & BOLT ASSEMBLY
NUT-10 UNC-2B, 3 NUTS
WASHER
NUT-11 UNC-2B
ICE SURFACE
NOT REQ'D AT A B OR C
WASHER
CAPSCREW-11 UNC-2A x 14 LG, 1½ LG. THREAD
NOTE - INSET NOT TO SCALE AND ONLY 5 OF 25 DRAWN
- SCARIFIER OPTION #2 USED FIVE 3/4" NUTS AT LEFT
ARCTEC CANADA LIMITED
16, 0325 - 11 STREET S.E.
CALGARY, ALBERTA T2H 2L8
DWG - ICF SCARIFIER
PROJECT - 856
SCALE 1"=2'
DWN - KPB
PROJECT MANAGER -
DATE - 22 MAR 82

with water ballast to provide good contact with the snow and ice surfaces (Photo 5). Primary scarifying refers to a single pass over the plot with the sled teeth set to a depth of 3.3 cm. Approximately eight traverses with the AST were required to completely treat the width of the plots (Photo 6). Secondary scarifying refers to a second pass on plots which had been scarified, using longer teeth settings on the sled to provide deeper penetration.

Tests of the icebreaking capabilities were based on previous experiences reported with the AST in salt water ice conditions (Mitsui, 1981). The AST had not been used for icebreaking in fresh water ice before the present project. Because of the greater strength of fresh water ice over sea ice and the expected thickness of the ice at Thunder Bay it was anticipated that the AST would not break the complete range of occurring thicknesses without assistance.

At the start of the test period ice thicknesses in the port areas varied from 65cm to 120cm. The region was scouted and two locations with thinner ice were found: one offshore the mouth of the Kaministikquia River (thicknesses of approximately 35cm to 45cm), and one offshore the mouth of the Mission River (open water to 75cm thickness). Refer to Figure #2 above. These areas were used to test the AST's icebreaking capabilities in increasingly thick ice cover. As the craft's operating range became more defined, various alternative driving techniques were experimented with in attempts to explore the upper limits of the craft's abilities.

At the ship berth of the Cargill Grain Corporation ice thicknesses ranged from 70cm to 85cm. There was no open water in this area. In order to initiate icebreaking, therefore an area of ice was cut up using chain saws and trenching equipment. This provided the initial "open water" required by the AST to break the ice. The ice thickness at this location exceeded the upper limits of the AST's capabilities for unassisted icebreaking. Therefore various ice cutting and slotting techniques were experimented with to allow the AST to break the ice. The objectives of this part of the program were to extend the AST capabilities efficiently, using a minimum of cutting for a

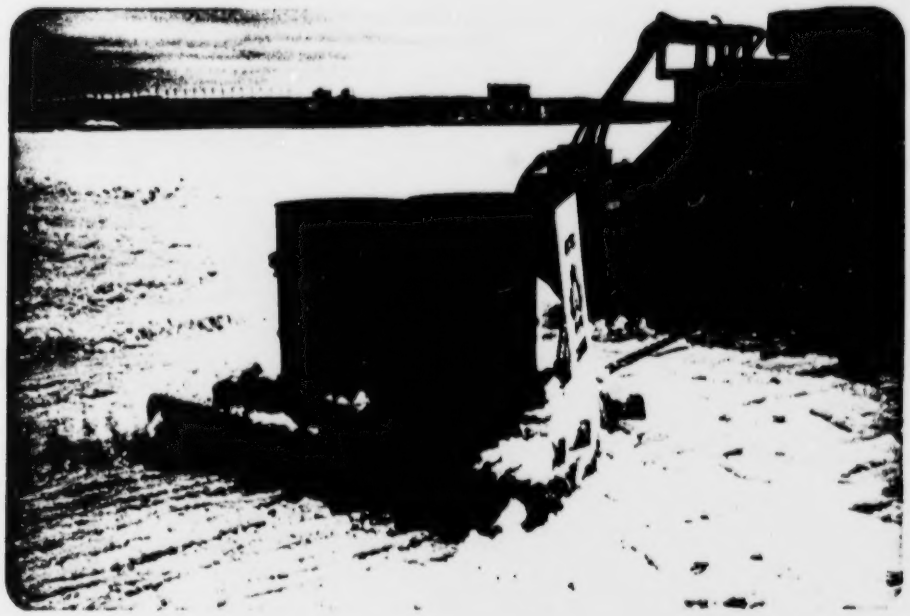


PHOTO 5

SCARIFYING SLED

PHOTO 6

SCARIFIED PLOTS

maximum of icebreaking.

An opportunity became available late in the test program to use the AST to break up river ice (at the mouth of the Neebing River) which had been previously fractured and cracked by dynamite. In these tests the AST was used in unassisted operations to fully evaluate whether the explosions had sufficiently weakened the ice for the AST to break it.

For evaluations of the AST as a personnel carrier and rescue vehicle, the day to day travel operations which the AST performed at Thunder Bay served well. In addition, specific efforts were made to travel across and within loose and refrozen ship tracks.

The testing of the AST as a tugboat vehicle was scheduled so that assistance to a coinciding test project, that of Air Cushioned Ice Breaking Bow (ACIB), could be given. Linking the ACIB to the C.C.G. Alexander Henry required tug operations which the AST could participate in. Unfortunately, delays with the ACIB project prevented this test and the AST was able to provide only slight assistance.

3. OBSERVATIONS

3.1 WEATHER OBSERVATIONS

Monthly Meteorological Summaries, as issued by Environment Canada for the Thunder Bay region, are included in Appendix C. Figures 6 through 12 show weather observations for the study period, taken at Thunder Bay airport by Environment Canada. The period of March 14 - April 5 was characterized by lower than normal mean air temperatures for both March and April and twenty percent less than the normal number of sunshine hours for March. Also in March, four times the normal amount of rain fell, while the mean maximum temperature was below freezing, resulting in many occurrences of freezing rain. During the first week of April almost 50% of the month's precipitation fell, much of it as snow. Relative to the other years, the small spring of 1982 can be characterized for Thunder Bay as arriving somewhat late and being much cooler with more snow and rain than usual. This weather situation affected the progress of the ice management plots (see below) to a high degree.

A summary of relevant meteorological events, taken from Appendix C, are given below:

Rain Light rain occurred twice in the early part of the study period - on the 11th and the 16th days. The heaviest rain occurred on the 17th day, totalling 23mm. Light rain again occurred on the 18th, 19th, and 21st days.

Snow Snow fell on fourteen of the twenty-two days of the study. Significant snowfalls occurred on the 5th day (5.5cm), the 11th day (4.5cm), the 20th day (4cm), and the 21st day (8.8cm).

Temperature There were only eight days with mean temperatures above freezing. These were the 2nd, 3rd, 4th, 8th, 11th, 16th, 17th, and 18th days. All others had mean temperatures below zero (Celsius).

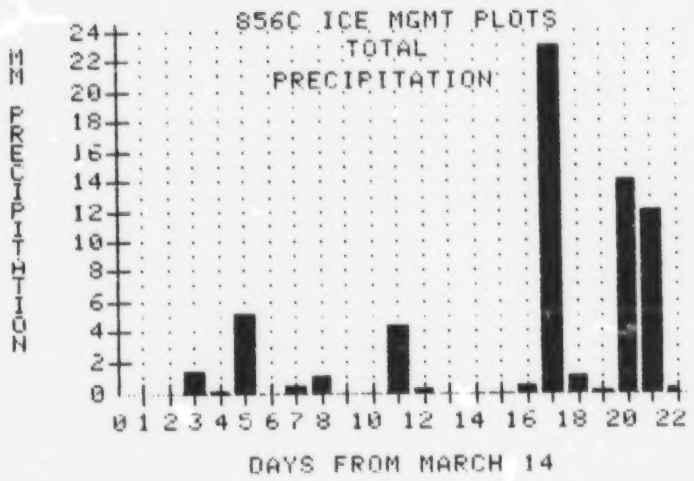

856C ICE MGMT PLOTS
TOTAL
PRECIPITATION
MM PRECIPITATION
0 2 4 6 8 10 12 14 16 18 20 22 24
0 1 2 3 4 5 6 7 8 10 12 14 16 18 20 22
DAYS FROM MARCH 14

FIGURE 6

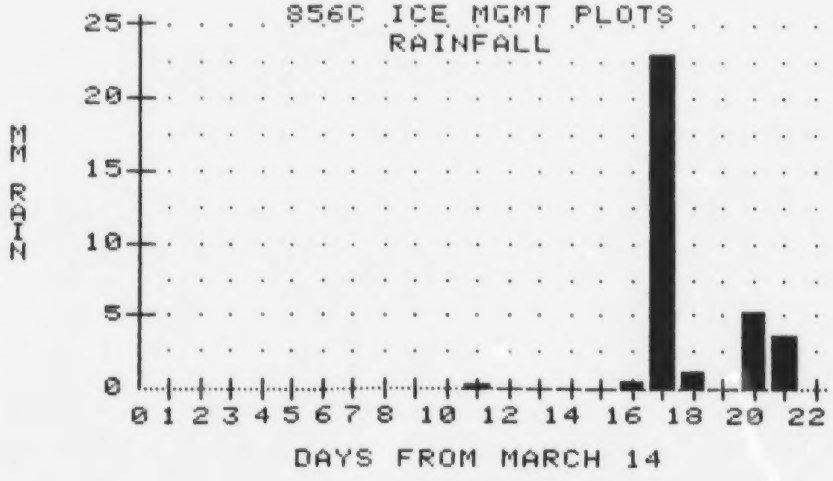


FIGURE 7

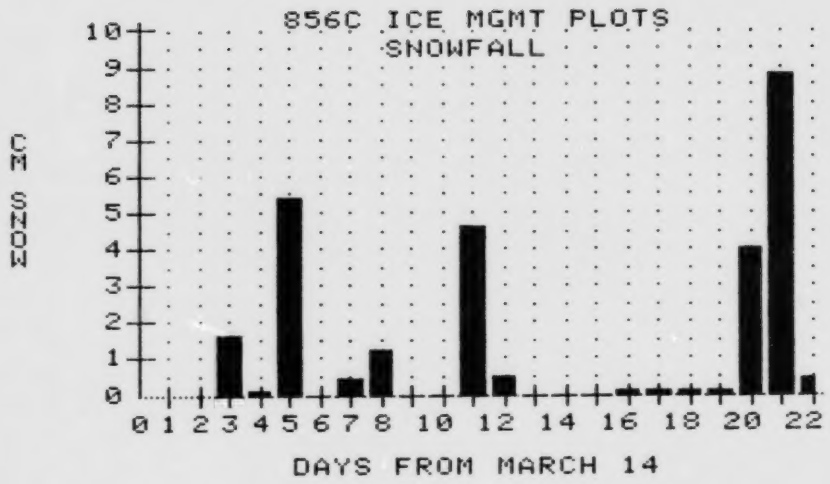


FIGURE 8

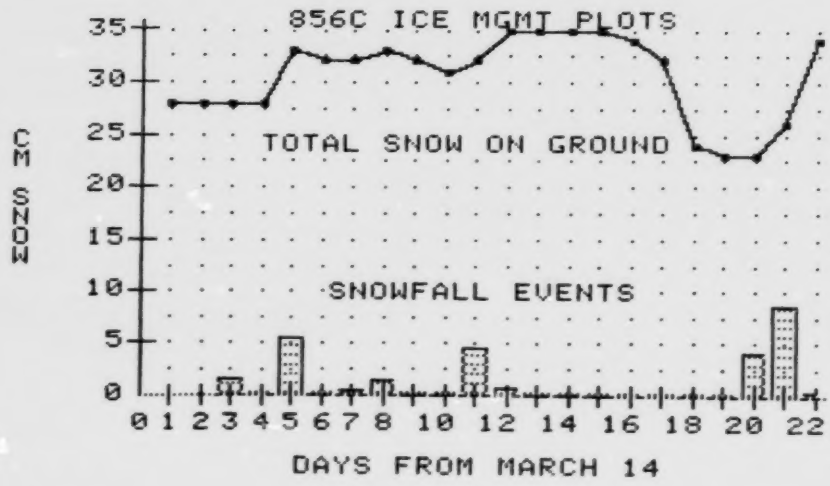


FIGURE 9

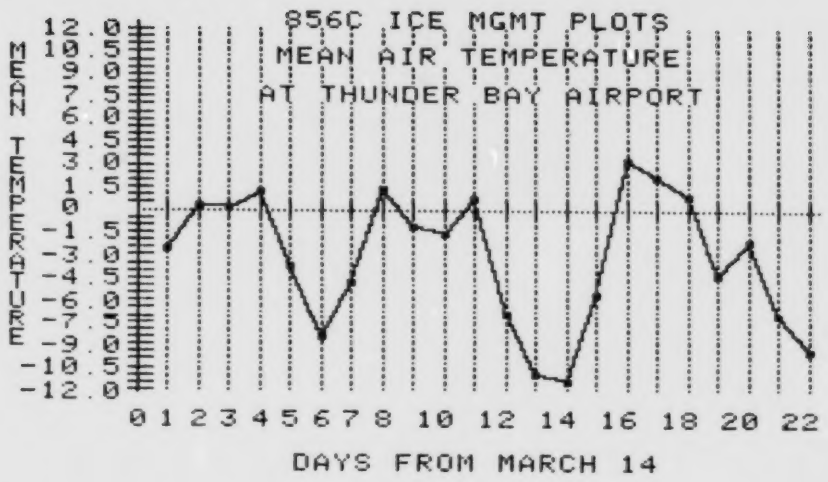


FIGURE 10

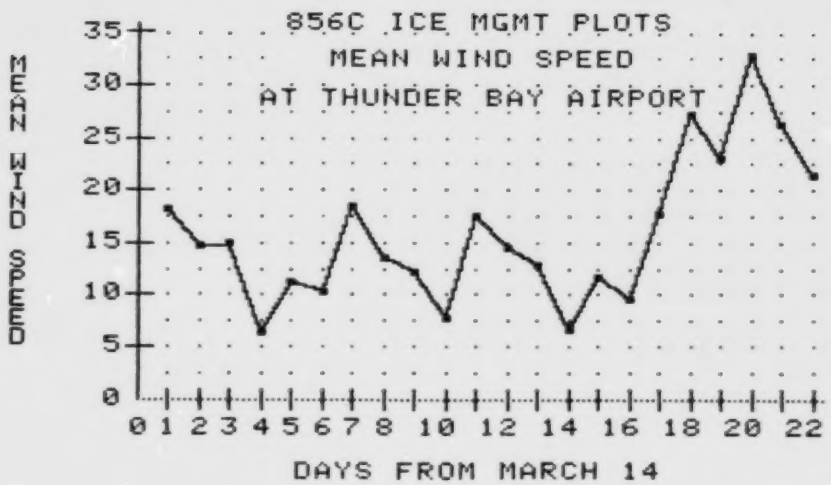


FIGURE 11

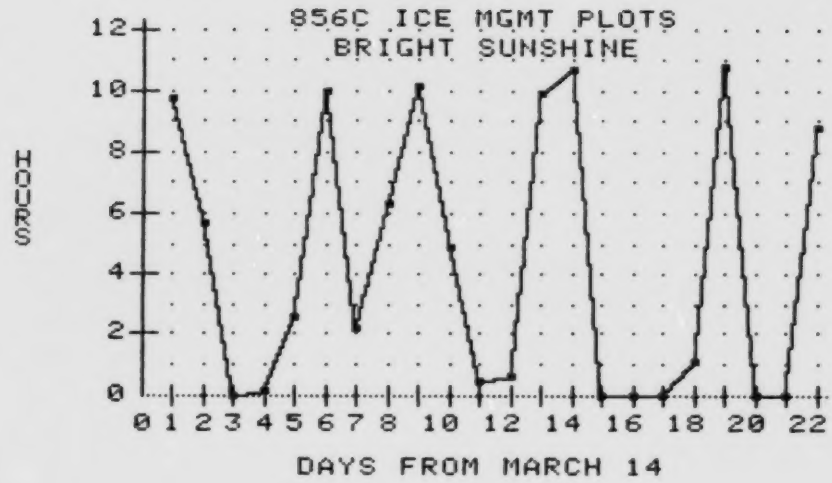

856C ICE MGMT PLOTS
BRIGHT SUNSHINE
HOURS
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 10 12 14 16 18 20 22
DAYS FROM MARCH 14

FIGURE 12

Sunshine The weather office recorded seven days with no sunshine. In a total of thirteen days there were less than five hours of bright sunshine.

3.2 ICE MANAGEMENT PLOTS

SNOW PLOUGHING

Equipment

The ploughing arrangement devised for use with the AST for these tests was an expedient and convenient one which did not require alteration of the prototype vehicle in any way (see Methods). AST production model ploughing accessories were likely to operate much more efficiently, effectively and suitable, using front-mounted blades and adjustable hydraulice. Nevertheless, the experimental plots were successfully ploughed by the AST. Problems encountered included the difficulty of finely controlled manoeuvering of the AST with the two rotors on vastly different tractional surfaces. The AST-002 was equipped with prototype controls which included short control levers. Considerable skill is required to accurately use these during difficult manoeuvers. Experience and increased driver skill obtained during ploughing helped overcome most difficulties.

General Observations of Ploughed Surfaces

The ice surface after ploughing was mostly cleared of snow, excepting some small windrows. The rotor flights from the AST marked the ice surface in regular patterns to depths of up to 6cm. In some places, surface water from previously melting snow or from ice thickness observation holes flooded the ploughed surfaces (Photo 7).

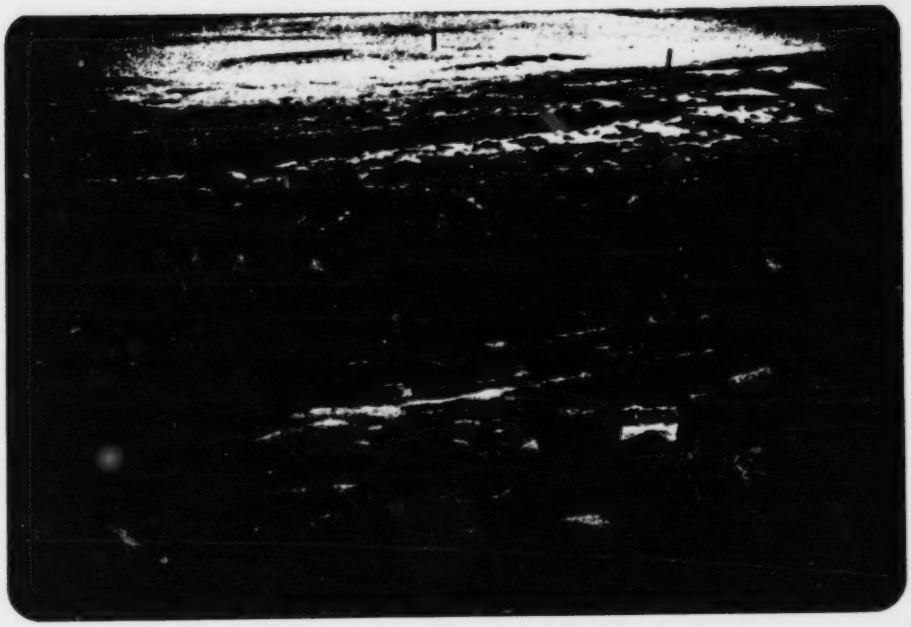


PHOTO 7

PLOUGHED SURFACE

After three days the ploughed surfaces were alternately exposed to several sunny and stormy days (including rain and snow) in a row. On sunny days the pools of surface water increased, (in places) up to depths of 10cm. Associated with sunny periods were cold nights, which resulted in complete freezing of the surface water into super-imposed ice. After some cold nights the daytime ambient temperatures were not sufficient to melt the super-imposed ice. Snowstorms did not result in significant accumulations on the ploughed surfaces. This is probably due to the winds (mostly from the west) which accompanied most of the storms, and to the smooth surface resulting from super-imposed ice. Rainstorms contributed accumulation in the form of water which was frozen to form additional super-imposed ice.

SCARIFYING

Equipment

The scale of the scarifying equipment was small relative to the capabilities of the AST. It is likely that larege pieces of machinery, similar in size to prairie farm equipment, would be effective for this type of operation.

The sled used in this test was not difficult for the driver to control, especially after the experience gained in ploughing operations. This sled produced "windrows" which were useful in guiding the driver and controlling the sled (see Photo 6, above). It is not certain how the windrows affected the speed of ice deterioration.

General Observations of Scarified Surfaces

The ice surface after primary scarifying was gouged to about 0.5cm deep. The pattern of the troughs was parallel on the outside of the "pass" and irregular toward the middle, due to "jitter" of the front of the sled. On the snow the troughs were the full length of the scarifying teeth, except where the snow depth was less than about 5cm (Photo 8). The depth of the

gouging varied perhaps 25% on both the snow and the ice surfaces, likely due to small variations in the running plane. Much of the snow cover was pushed aside into windrows by the wedge shape of the sled.

Secondary scarifying created troughs in exposed ice not significantly deeper than those created from primary scarifying. The sled was less stable on exposed ice because of the longer teeth. In snow, secondary scarifying produced deep and well formed troughs, averaging 9.5cm deep. The longer scarifying teeth were damaged by bending, most likely during travel over ploughed ice, where ruts from the AST rotors were encountered (Photo 9).

During succeeding sunny days little change was observed in these plots. After cold nights which followed sunny days, the snow pack became very "stiff" in the morning and ambient temperatures were not high enough on a number of occasions to soften it. The rainstorms contributed to some melting of the snow. This water may have added to the super-imposed ice on the ploughed areas or may have refrozen as ice in situ. Much of the scarified area became ice covered during the storms which occurred , leaving a firn-like ice instead of snow. This super-imposed ice remained frozen for the interim.

DUSTING OPERATIONS

Equipment

Accessory equipment to be attached to the AST for dusting of the ice and snow surfaces was not developed during these tests due to the limited areas that the technique was applied to. A small hopper/spreader for hand application was used unsuccessfully, due to the fine particle size of the dusting material used. In production operations, a mechanical or air-blown system, similar to applications in the agricultural industries, would be suitable. Application during this project was quickly accomplished by hand.

The material used was grain dust, acquired from the local elevator operators. The particle size varied considerable, but was generally fine (because the size ranges were inconsistent from each sample, these were not measured).

PHOTO 8

SCARIFIED SURFACE

IN SNOW

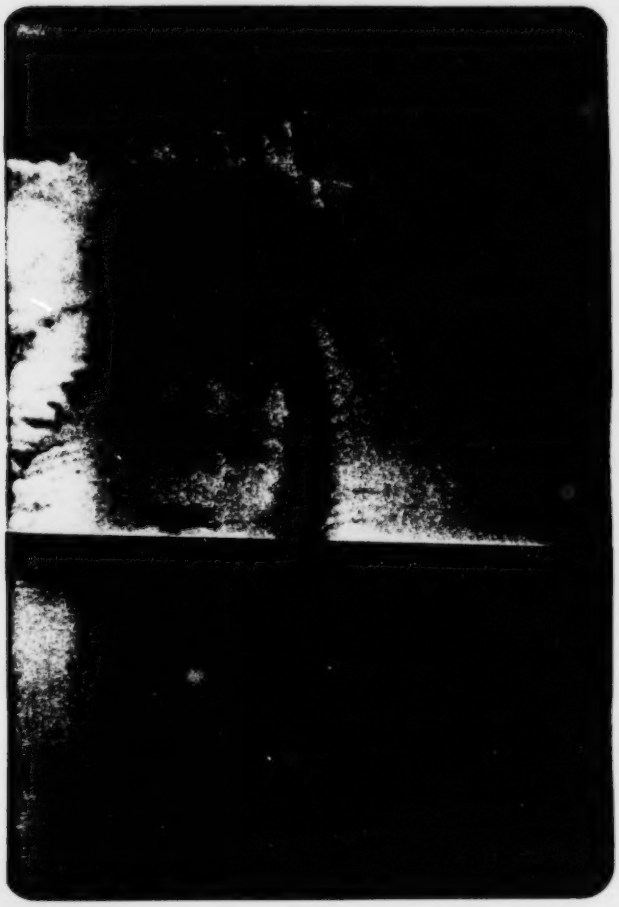


PHOTO 9

DAMAGED (Bent)
SCARIFIER (TEETH)

Approximately 1/3 cubic metre was applied to the plots (equivalent to approximately .02kg/m^2).

General Observations

Although wind currents redistributed some of the material, most of the dust became affixed to the snow and ice surfaces immediately (Photo 10). Subsequently, some of the ploughed areas were flooded by rain and melting snow. Flooded surfaces became frozen during cold weather which followed. Observations of these surfaces indicated that some surface melting and softening occurred in the dusted plots. Ice surfaces in the dusted areas "crackled" under body weight, indicating weakening. During sunny days with below freezing temperatures, dusted snow was observed to melt 2cm in a 24 hour period (Photo 11, Photo 12).

CONTROL PLOTS

The control plots were not modified at all after ploughing had occurred. This left two areas with undisturbed snow and two areas which had been ploughed only. Flooding occurred on the ploughed plots similar to the other areas and may even have occurred to a greater extent due to apparent lower freeboard of these particular locations. This became frozen later as super-imposed ice. The snow covered areas began to deteriorate slightly during the warm sunny days but experienced glazing during the freezing nights. After the occurrence of the rainstorms, the snow pack was virtually all converted to firn-like ice and became super-imposed ice. This was strong enough to carry body weight with no apparent effect, and when drilled through was solid ice.

PHOTO 10

DUSTING OPERATIONS

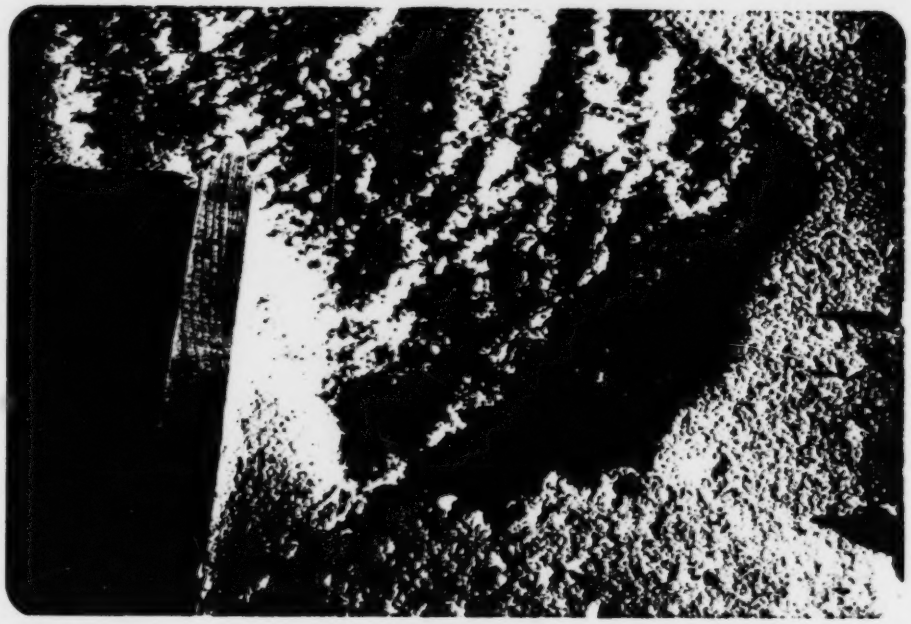


PHOTO 11

SNOW MELT IN DUSTED PLOT

PHOTO 12

DUSTED PLOTS

ARCTEC CANADA LIMITED

RESULTS OF ICE THICKNESS OBSERVATIONS

Control Plots

General Observations (Fig.13)

The overall trend of the ice thickness in these plots was of increasing thickness, totalling 6cm. Up to the 19th day of testing (April 1) observations show a marked increase in thickness. However, the rate of increase in thickness falls off after this point.

Snow Covered Control Plots Observations (Fig.14)

This area generally increased in thickness throughout the period except about April 1, when the thickness is shown to have decreased. The total overall increase is 8.9cm. It appears that melting snow was refreezing at the ice surface and becoming super-imposed ice, contributing to greater thickness. Rain previous to the 19th day may have melted some of this material and transported it to the nearby ploughed areas, temporarily decreasing the thickness.

Plowed Control Plots Observations (Fig.15)

The ploughed control plots generally decreased in ice thickness except about the 19th day (April 1), totalling 7.6cm reduction. The overall ice thickness decrease is difficult to explain with confidence because of the low ambient temperatures of this period. It appears likely that melting was occurring from below the ice sheet and this may have been assisted on the ploughed areas by allowing greater heat flux down on warm days without the insulating snow cover. Because of the rain and warm temperatures on the 17th day, it is likely that flooding of the ploughed areas occurred, with sources of water including rain run-off and melted snow from nearby plots.

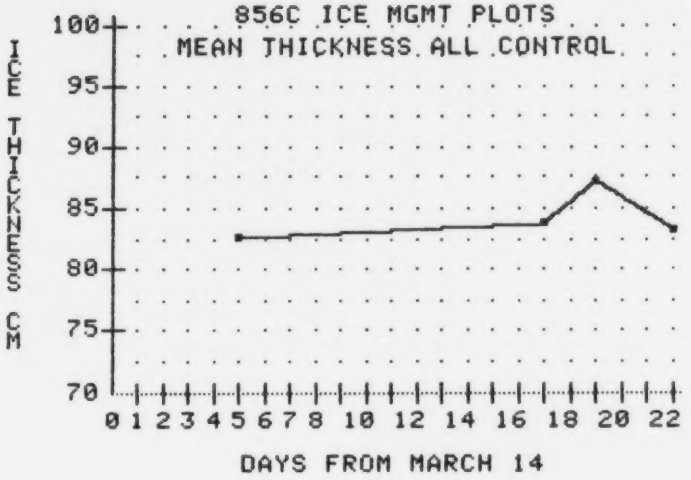


FIGURE 13

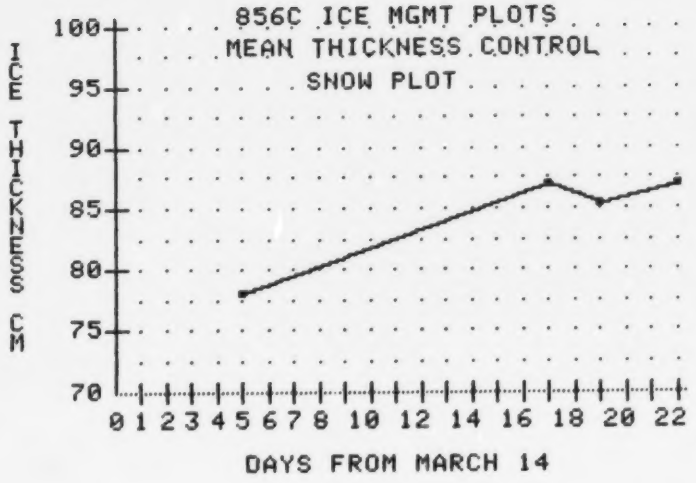


FIGURE 14

SCARIFIED PLOTS

General Observations (Fig.16)

For all the scarified plots taken together, the observations show a net zero change in ice thickness. These integrated observations show a general increase in ice thickness to March 30 then a rapid drop to Arpil 1 followed by a thickness increase again.

Primary Scarifying

General (Fig. 17)

These areas showed an overall reduction in ice thickness. Up until the 17th day the thickness increased slightly then dropped off. Overall change was 2.1cm.

Snow Covered Primary Scarified Plots (Fig. 18)

These plots showed a general increase in ice thickness totalling 1.3cm. A reduction in ice thickness was indicated on the 19th day, however. It is likely that the general increase in thickness is due to acquisition of superimposed ice from freezing of melted snow.

Ploughed Primary Scarified Plots (Fig.19)

The ploughed plots indicated slight increases in ice thickness during the first part of the study period then showed a rapid decrease after the 17th day. Total decrease was 4.8cm. Similar to the control plots, above, the exposed ice here appears to have melted from below. Lack of snow insulation during the early part of the study while temperatures were warm may have allowed this ice to warm up enough to aid melting and contribute to general thickness reduction.

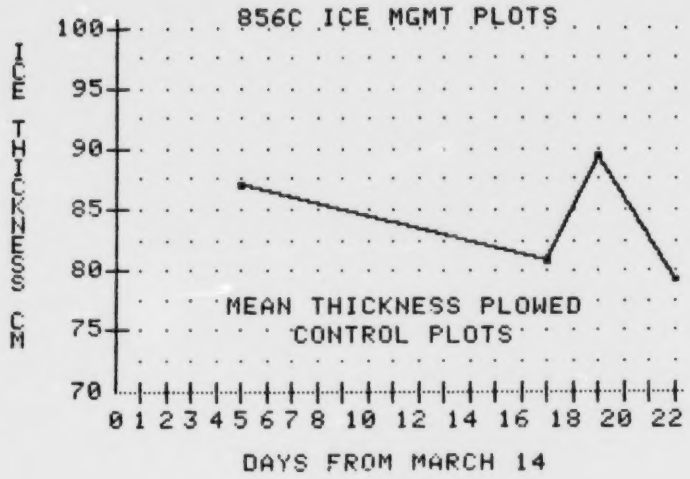


FIGURE 15

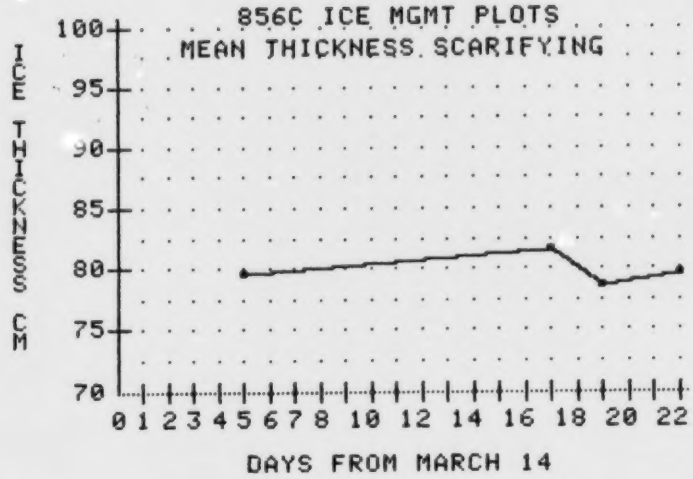


FIGURE 16

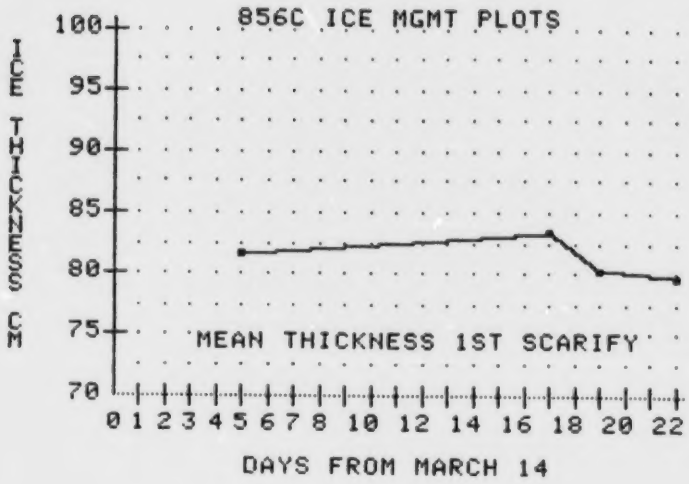


FIGURE 17

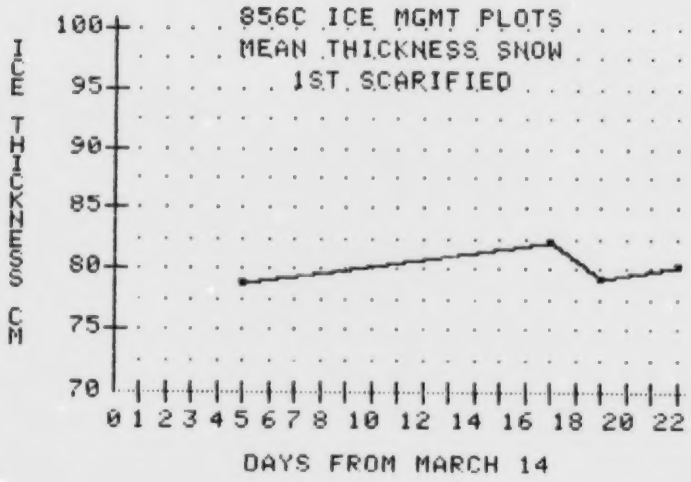


FIGURE 18

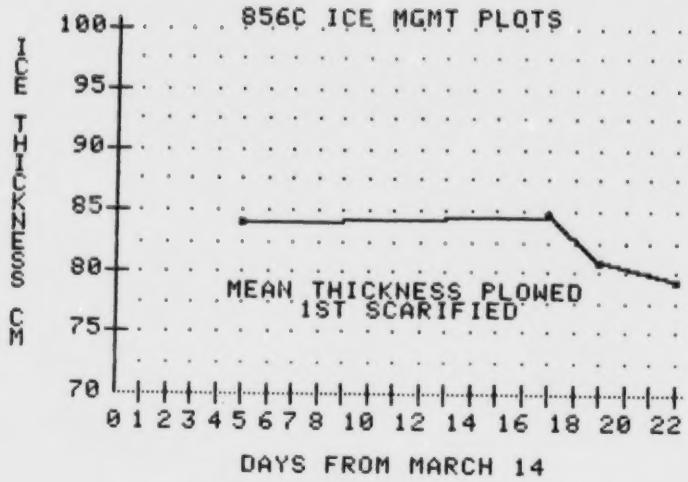


FIGURE 19

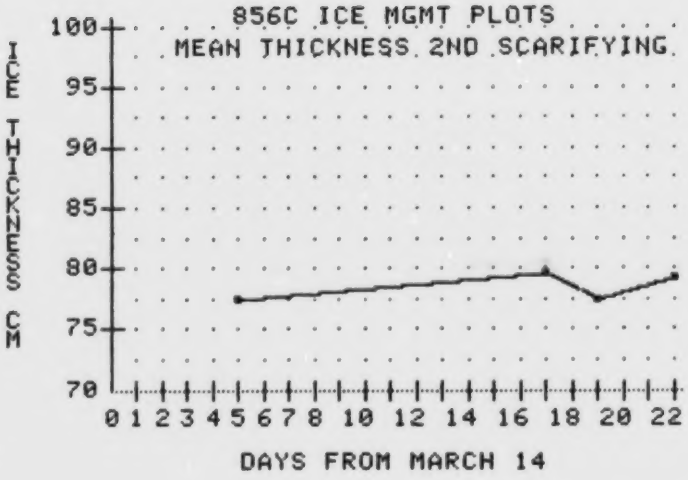


FIGURE 20

Secondary Scarifying

General (Fig.20)

A general increase in ice thickness was observed for these areas, totalling 1.9cm. The ice thickness decreased somewhat about the 19th day.

Snow Covered Secondary Scarifying (Fig.21)

These two plots experienced a general increase in ice thickness for the period, excepting the observations from the 19th day (April 1). The overall increase was 3.6cm. Melting snow water which percolated through the snow pack and refroze on the ice surface to form super-imposed ice is thought to have contributed to this increase.

Ploughed Secondary Scarifying (Fig.22)

These plots showed no overall change in ice thickness. The ice thickness decreased slightly to the 17th day, then more rapidly to the 19th day followed by a sharp increase to the end of the period. It is difficult to explain the changes which occurred in these plots. It is interesting that many fluctuations shown at the other locations are "damped" out here. One possible explanation is that the resulting snow cover left after scarifying was sufficient to provide a source of melting snow water which closely balanced the loss to the ice sheet from melting at the lower surface.

DUSTED PLOTS

General (Fig.23)

The dusted plots generally decreased in ice thickness throughout the period, with a faster rate shown on the 19th day. Total decrease was 2.8cm.

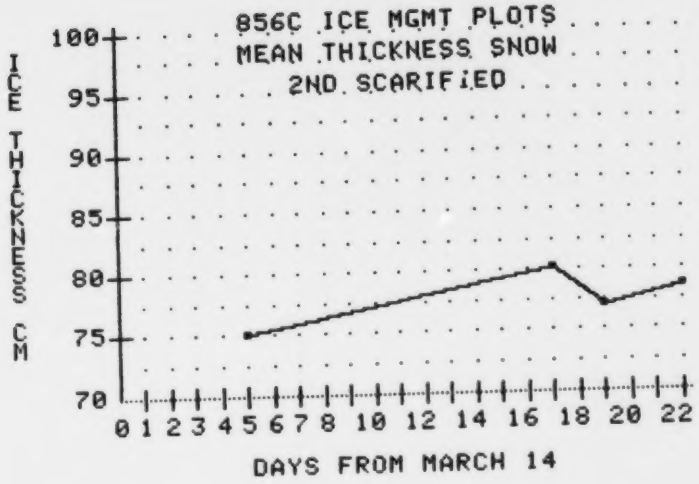


FIGURE 21

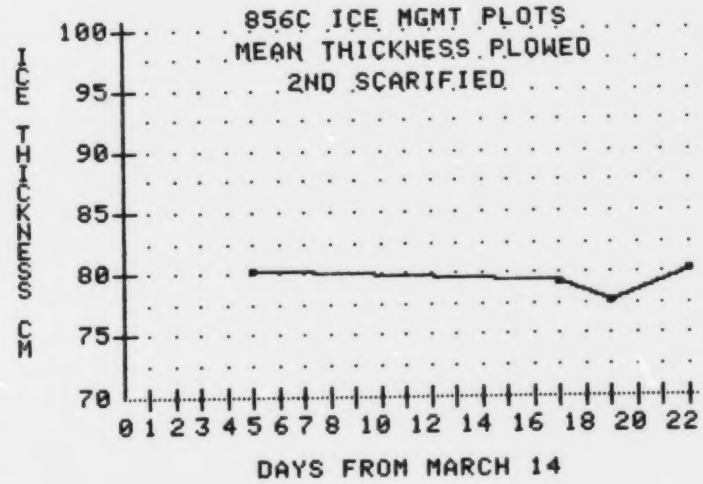


FIGURE 22

Snow Covered Dusted Plots (Fig.24)

Ice thickness in these two plots decreased generally, and the rate increased about the 19th day (April 1). The total decrease in thickness was 7.9cm. Observations of the snow surface, even after rain glazed it, indicated that sublimation may have been occurring: small craters surrounded the dust particles, filled with dry, loose ice crystals (see Photo 10, above). Apparently rain and sun-melted snow was not refreezing as completely in these areas and not contributing substantially to super-imposed ice. If the ice was melting from the lower surface of the ice sheet then this would account for the overall reduction in thickness.

Ploughed Dusted Plots (Fig.25)

The ploughed dusted plots were observed to increase in ice thickness overall for the study period. Ice thickness decreased slightly to the 19th day, then increased sharply to the end of the study. Total overall increase was 2.4cm. The rain and snow coupled with low temperatures, which occurred after the 19th day, may have contributed to the overall increase in ice thickness for these plots.

Summary of Plot Observations

The snow-covered plots all have very similar looking graphed observations except for the dusted plot. Most generally increase to the 17th day, decrease to the 19th day, then rise to the end of the study period. However, the dusted snow-covered plot decreases steadily.

The graphs of the ploughed areas are not as similar to each other but they generally exhibit a decrease in ice thickness, though none so great as the snow covered dusted plot (Figure 24, above).

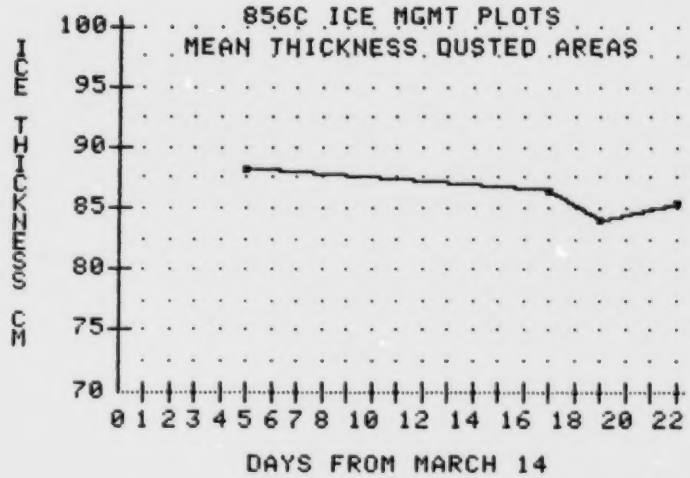


FIGURE 23

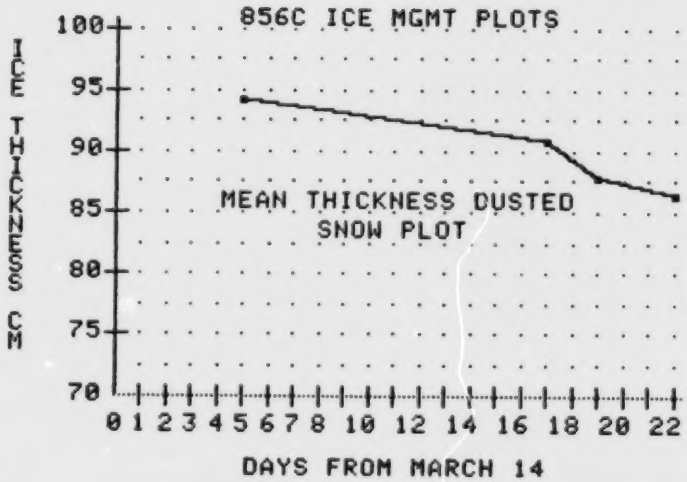


FIGURE 24

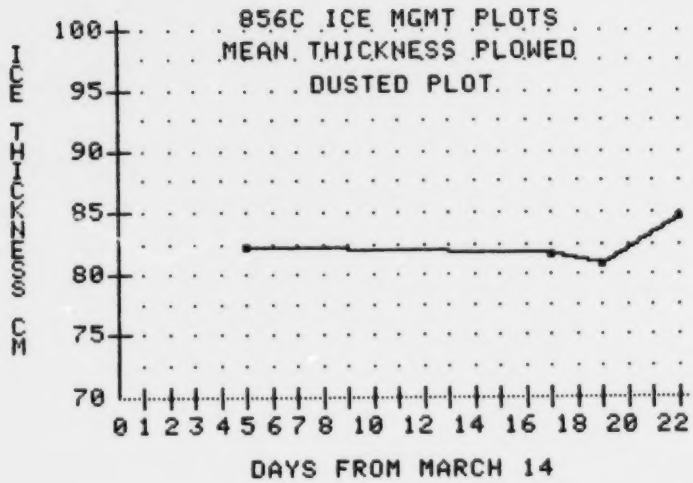

856C ICE MGMT PLOTS
MEAN THICKNESS PLOWED
DUSTED PLOT
ICE THICKNESS CM
100
95
90
85
80
75
70
0 1 2 3 4 5 6 7 8 10 12 14 16 18 20 22
DAYS FROM MARCH 14

FIGURE 25

Interpretation of this data must be cautious for several reasons. The weather which occurred during this period was cool or cold for extended periods with several rainfall events; these served to contribute additional ice thickness through accumulation of super-imposed ice. The overall changes in ice thickness, whether increases or decreases, are not great and compared to the normal variations of ice thickness in the area are not considered significant. Additionally, meteorological records for the period the Thunder Bay airpoit indicate that compared to "normal" years, the weather conditions for this spring were generally cooler, less sunny and much rainier.

Therefore, the results of the techniques applied to the ice and snow surfaces should not be considered conclusive. While the data suggests that dusting of snow-covered areas will contribute to ice thickness reduction and that ploughing snow off the ice will also do this, the complex and varied weather conditions which affected the experiments over the study period make firm conclusions unwarranted.

3.3 ICEBREAKING OBSERVATIONS

The AST was used in a variety of situations and configurations to break ice at Thunder Bay. Some of these employed the use of accessory equipment, while others involved the AST alone. These are discussed below with a description of the method used, the ice thickness, the results of the method and comments resulting from the observations and results.

Method A.1. AST Alone, Normal Mode

This method is standard icebreaking mode for the AST. The craft starts from open water and approaches the ice perpendicular to the edge. When it encounters the edge it climbs slightly on and fails the ice by the application of its weight (see Photo 13). The craft proceeds through the broken pieces of ice, approaching the new ice edge where the process repeats itself. Through increasing ice thicknesses this process continues until it is no longer possible to break the ice. The AST then climbs onto the intact ice sheet and continues running on the surface. This method operates in fresh water ice from zero to 45cm.

The results of this method are broken ice pieces which lie mainly in the vehicle track (Photo 14). Piece sizes range approximately from .75m to 3m on a side. As the vehicle progresses in the track, before climbing on-to the ice, observations showed that occasionally much larger ice pieces will break off to the sides of the track. These pieces are very long and narrow strips parallel to the first ice edge (Photo 15). Results of this method are greatly enhanced if winds are assisting to drive ice away to open water as it is broken off, apparently relieving jamming along the ice edge.

By using this method tracks may be set into the ice edge every 30 to 50 metres to effectively fracture the ice edge. Unless ice is cleared away, however, there may not remain room enough for the ice to expand and separate, reducing the effectiveness of the method.

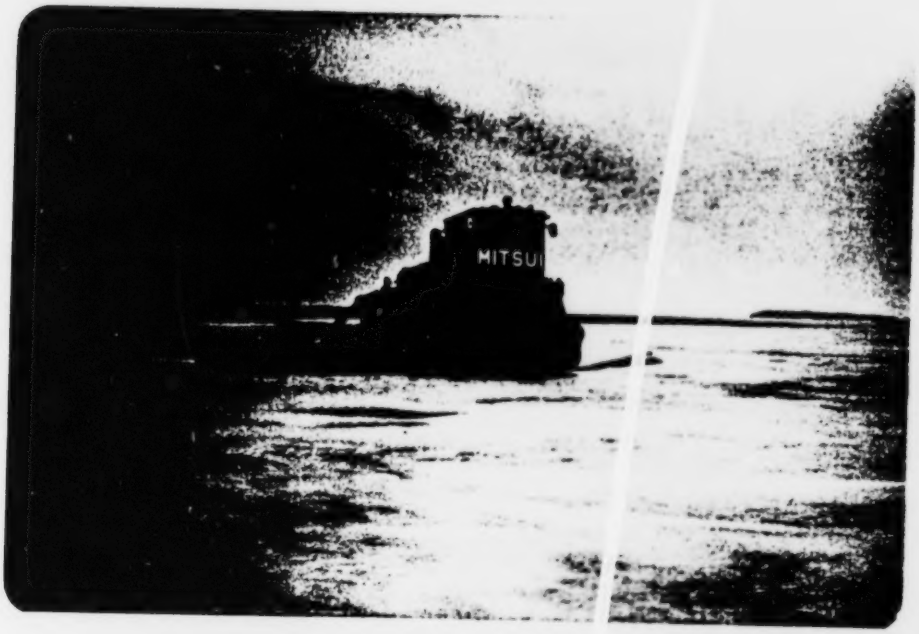


PHOTO 13

NORMAL ICEBREAKING

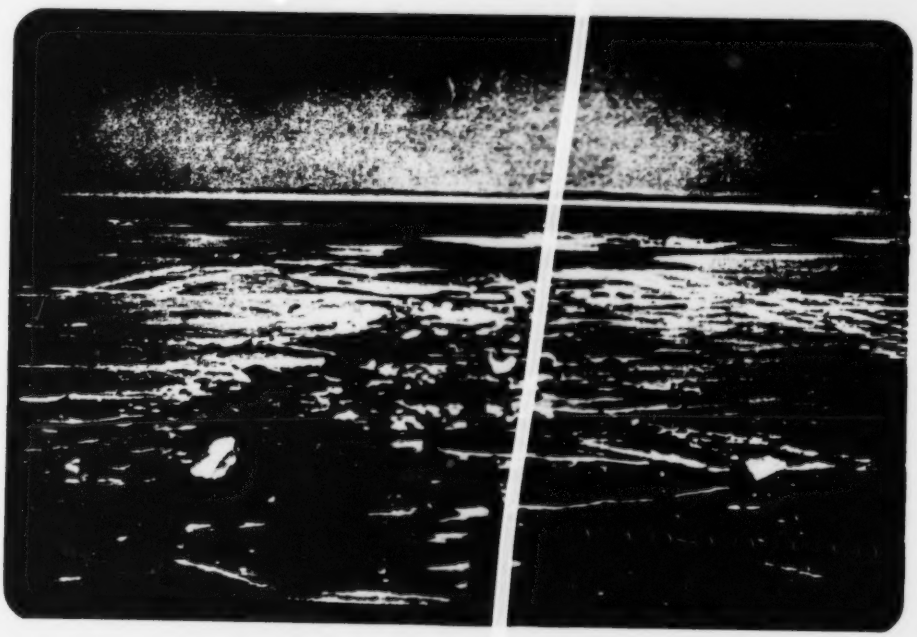


PHOTO 14

BROKEN ICE IN A T TRACK

Method A.2. AST Alone, Variations on Normal Mode

These methods are the same as in A.1, but when normal icebreaking is stopped due to thickness or pieces jam up to prevent further breaking, the AST driver may use techniques to continue progress further. These are mainly: (1) stopping the vehicle poised on the ice edge momentarily; (2) backing the AST off the edge and driving back on; (3) rocking the AST on the ice edge with forward/reverse motions; and (4) slamming the ice surface just forward of the edge by quickly driving over the ice edge. These techniques, especially the first three, are especially useful because of the high degree of control inherent in the craft when performing them. These techniques extended the vehicle capabilities to 55cm (see Photo 16).

Although somewhat slower, these methods make use of A.1 and extend the time and area of broken ice for each run. For technique (1) the ice fractures slowly (cracks appear), then the ice fails and the ice and vehicle drop to a floating point of equilibrium. Ice is broken in a semi-circle forward and under the machine. In (2) the ice breaks mostly within the area of the vehicle track, unless (1) is added. The combination serves to break ice beyond the track width of the craft. Using technique (3) the ice cracks for several vehicle widths and breaks primarily under the track, but often in large strips to either side. Using (4), large ice pieces, sometimes a great distance to the side, may be broken off.

These methods used with several adjacent runs into the ice edge are more likely to break large areas of ice than A.1 alone because cracks are formed which join each broken track. So, although each run takes more time, each run is also much more effective. It should be noted, however, that driver fatique increases considerably with such manoeuvers.

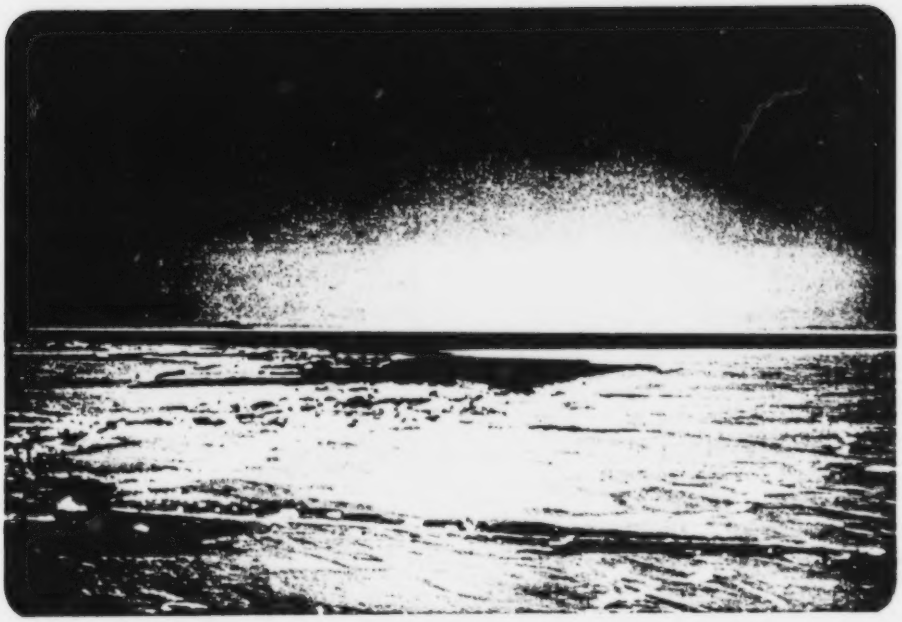


PHOTO 15

FRACTURE CRACKS TO SIDE OF AST TRACK

PHOTO 16

BROKEN 50 cm ICE PIECE

Method A.3 Further Variations on Normal Mode

This method involves running the AST along the ice edge, or parallel to it, prior to using methods A.1 or A.2. By operating at low speed and about 2m from the ice edge, cracks are formed which extend several vehicle widths into the sheet. The resulting free end beams are strong enough to support the craft but the cracks between the beams can be used as failure planes as described below. Several passes may be made over each vehicle width and/or passes may be made for several vehicle widths from the ice edge, in order to extend the effect.

By listening to the cracking of the ice as the AST passed over, one could judge how many passes were required to fatigue the sheet. If the AST operated too far from the edge (approximately 4m for 60cm ice), no effect took place. If it operated 1m or less from the edge, it often broke the ice, slipped at least one rotor into the water and had to circle around to regain the edge. With two passes in 63cm ice the A.2 type method would break up to three AST lengths and 10 to 20 widths on either side of the track. Resulting pieces were of various sizes, averaging about 5m per side. Using more than three "lanes" or widths from the ice edge did not seem to greatly enhance breaking capabilities.

Although each run is again slower, this method breaks much greater areas of ice up to 55cm thick and allows breaking of ice past 75cm thick. For each hour of vehicle operation and for swiftness of ice melt after breaking, this method is likely most efficient when the ice is more than 50cm thick. Approximately 4.9 hectares of ice were broken during experimental work and 50% of this area was broken using method A.3 for approximately the same time that A.1 and A.2 were used on the other 50%.

This method was found to extend the craft's icebreaking capabilities to ice as thick as 80cm.

Method B Techniques

Most of the following methods were used in very thick ice (70 to 85cm) and required a small open water area to begin icebreaking. These methods were dependent on slots or holes cut through the ice by mechanical means. At the Cargill site this was an area cut out of the ice to waterline with pieces 2m by 3m, totalling an open area of about 6m by 12m. The techniques were then applied to the ice in advance of the open area. The open area increased with successive tests. The AST was driven across the open area and toward the ice edge where the methods were being applied.

Method B.1. Assisted Icebreaking - Perpendicular Slots

Three slot types were cut perpendicular to AST travel path. The cuts were 2m away from the open area and parallel to one side of the open area (refer to Figure 26).

(a) shallow slot 30cm deep. Results: no ice broken
(b) deeper slot 45cm deep. Results: no ice broken
(c) slot cut through to water, 75cm deep. Results: no ice broken

This method did not assist icebreaking.

Method B.2. Assisted Icebreaking - Parallel Slots (Beams)

Two parallel slots were cut, parallel to the direction of craft travel, 6m apart (refer to Figures 27a and 27b). These were first made 8m long. Results: a beam broke which was 8.6m long (just past the end of the slots). Then a pair of 20m long slots were made similarly. Results: the beam broke in three places (Photo 17). The pieces were 9m, 8m, and 2m long, respectively. By accident, the width between the two slots widened toward the end, reaching nearly 10m in total width.

Method B.3. Assisted Icebreaking - Chevron Cuts

A "V" shaped cut was made at the end of the open area, with the point toward the on-coming AST. The cuts were each about 8.5m long and extended 7m from the ice edge, and to 10m apart at the open end (see Figure 28). Results: the ice was broken quite easily into three or four pieces. The total area broken was not as much as in B.2, but the pieces were much smaller. The resulting broken area was not as well defined, either, having jagged edges. These edges were not sufficiently jagged, though, to provide opportunities for easy additional breaking.

Method B.4. Assisted Icebreaking - Extended Parallel Slots

These tests were conducted as in B.2 but used the following wider areas (see Figure 29):

(a) 10m wide beams, 20m long. Results: the ice did not fail on the first pass of the AST, but did on the second, breaking into at least five major pieces.

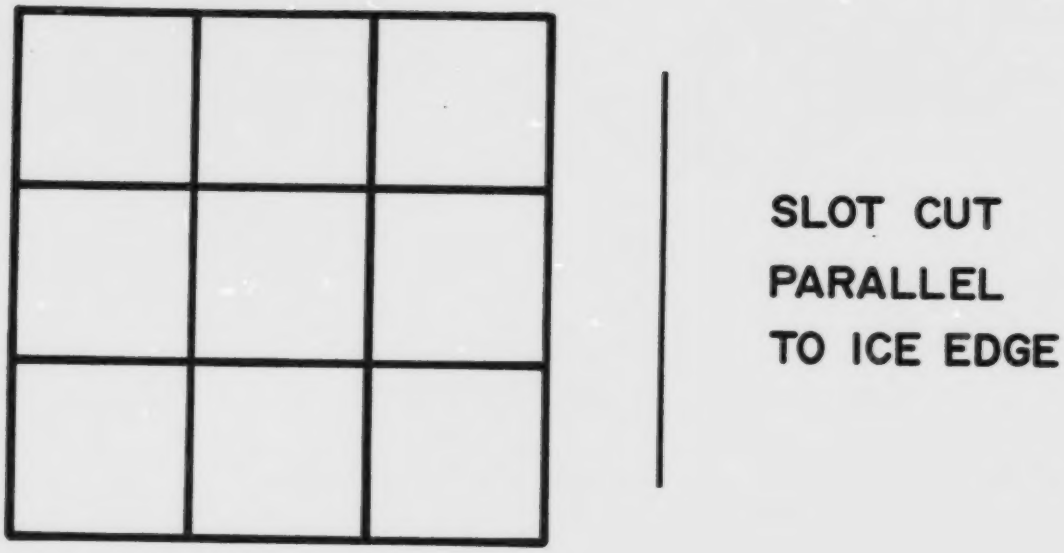
(b) 15m wide beam, 20m long. Results: ice was not broken. These tests assisted in recognizing the limits of these methods, and are further referred to in Section 4-Calculations.

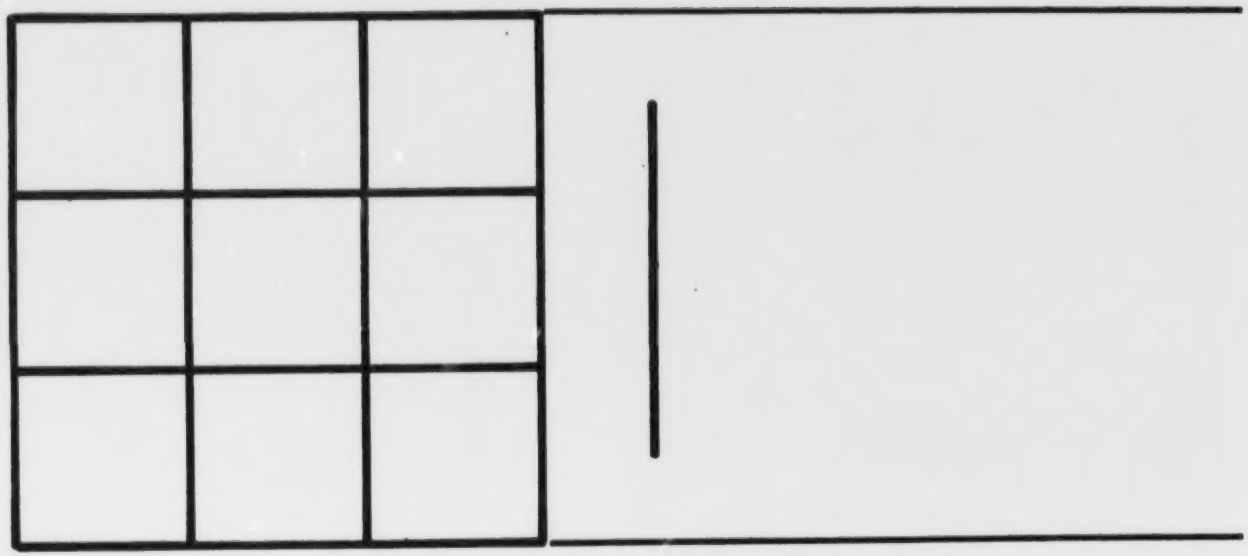
Method B.5. Assisted Icebreaking - Dynamite Preparation

The Neebing River, south of Keefer Terminals, is prone to spring flooding annually. The City of Thunder Bay uses dynamite to break up and crack the ice in the river initially (Photo 18), and a local tugboat to move the ice pieces when the river level begins to rise. Because the river is shallow, tugs cannot work very far up from its mouth.

Blasting on the Neebing River took place from March 24 to March 26. On April 1 the AST was used to break up portions of the dynamited river at the lower end (Photo 19). The ice thickness on the river varied from 30cm to 75cm,

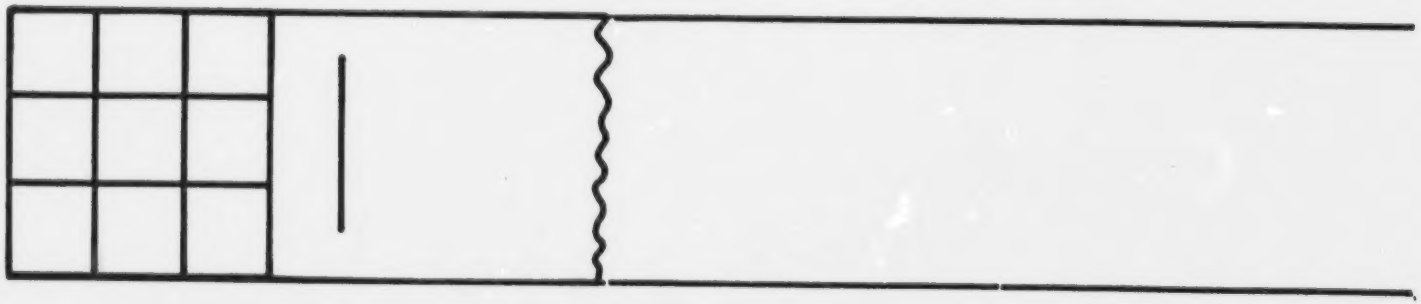
Figure 26





8 m LONG
PARALLEL SLOTS CUT

Figure 27a



20 m LONG

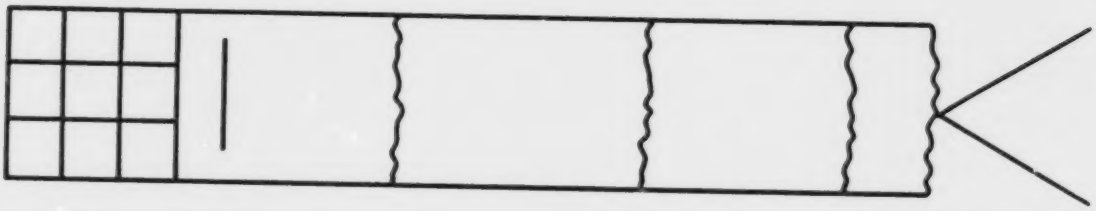
PARALLEL SLOTS CUT

Figure 27b

PHOTO 17

ASSISTED ICE BREAKING USING SLOTS

Figure 28



CHEVRON
SHAPED
SLOTS CUT

FIGURE 29

EXTENDED WIDTH PARALLEL SLOT

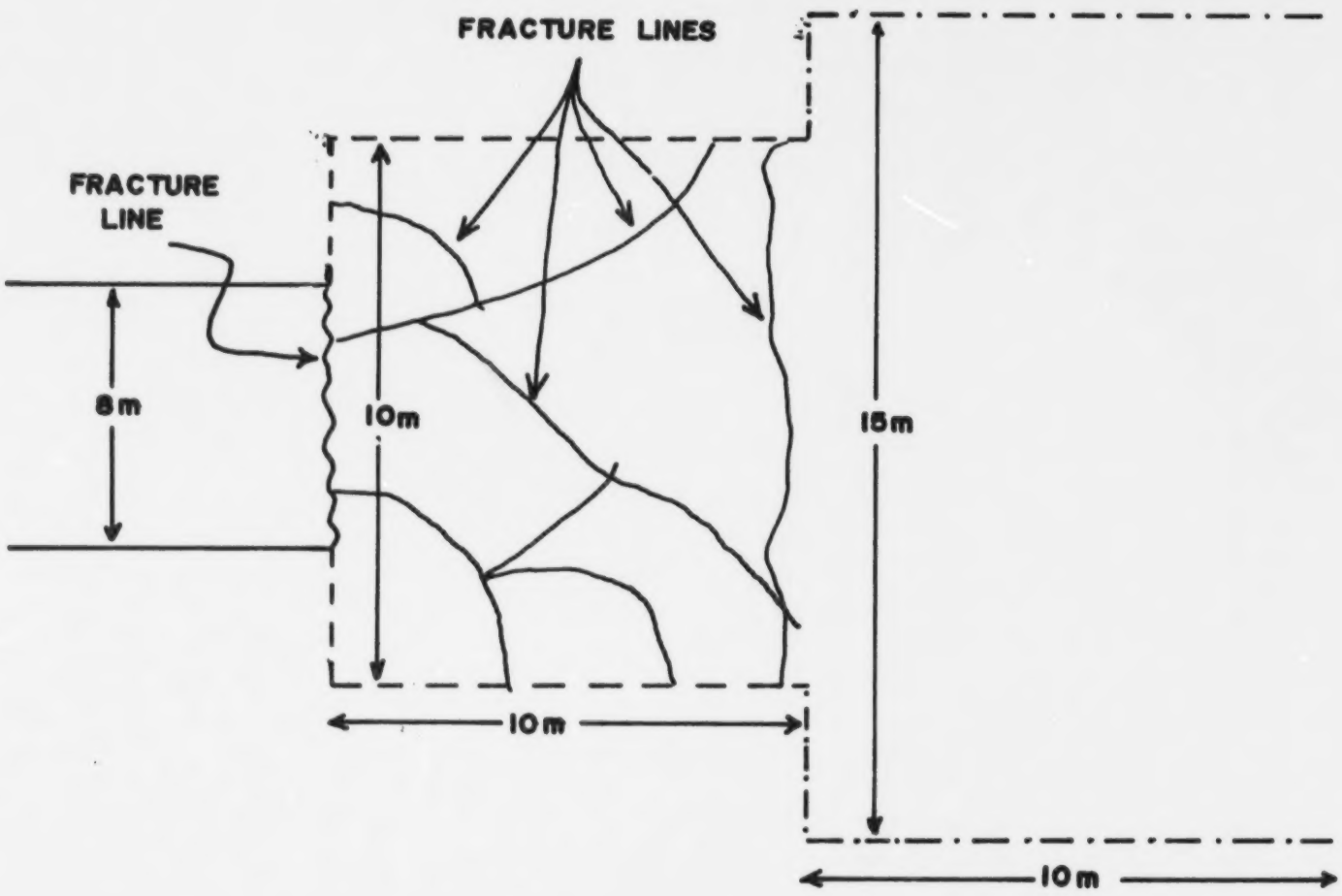


PHOTO 18

NEEBING RIVER: DYNAMITE CRATERS

PHOTO 19

NEEBING RIVER SHOWING ICE BROKEN BY AST

with much ice grounded. Some difficulties were encountered due to the shallow depth of the river, which prevented ice pieces from being displaced by the AST and which also allowed the rotors to encounter the rather adhesive bottom sediments, causing power loss problems for the craft.

When the river depth allowed, however, the AST easily broke up the fractured ice into small pieces (average 10cm across).

General Observations of the AST as an Icebreaking Vehicle

Although the craft is well designed for the icebreaking roles and performs well, some design features prevent it from completely fulfulling its capabilities. The incorporation of the hydraulic motors on the aft ends of the rotors leave these motors exposed to potential damage from ice, docks and other objects. This design also prevents the AST from being able to climb out of water onto ice in reverse.

3.4 OBSERVATIONS OF THE AST AS A TRACTOR/TUG

The AST had no difficulty at all in pulling the small loaded sleds which were constructed for ploughing and scarifying. Some difficulty was experienced in manoeuvering it while trying to direct the sleds on a specific course when the AST was travelling on two different surfaces at the same time.

The AST was used to assist the towing of the Air Cushioned Ice Breaking Bow (ACIB) being tested at Thunder Bay concurrently. There was some opportunity to directly pull the ACIB from land to water, downhill, but no opportunity to tow the ACIB over level ice directly. The AST was used to pull the ACIB from the side while it was towed by a tug boat. The AST has poor pulling ability when the load is oriented to the side because traction-al capabilities are best in the fore-aft direction. The craft gets pulled around if it attempts to tow from an angle of more than approximately 10 degrees.

The AST-002 is not able to pull a load very effectively in either broken ice or open water. In broken ice its attitude varies a great deal and orientation to the load is a problem. In open water the draw-bar pull is only about one tonne.

It was not possible to ascertain the capabilities of the AST for pulling large loads on level ice during these tests because the ACIB was not available. The upper limits of the torque capabilities of the hydraulic system were illustrated, though, when on one occasion the craft sat overnight in 15cm of water which became frozen. The next morning the AST was unable to break out of this ice, and required assistance from a large fork-lift truck.

3.5 OBSERVATIONS ON MULTI-PURPOSE VEHICLE USE: TRACK CROSSING, RESCUE, PERSONNEL AND CARGO CARRYING

TRACK CROSSING

The ship tracks which were available in the port area were created by the CCGS Alexander Henry. The degree of reconsolidation in the track was sufficient to allow foot crossing with care. The refrozen ice was 10 to 15cm thick.

The AST encountered no difficulties in crossing ship tracks in ice, whether refrozen or not. It always rebroke the ice if the track had froze. The AST was highly manoeuverable and could be steered with considerable accuracy and speed (up to 3 knots or 1.17m/sec) even among large ice pieces. The comfort level of passengers on the AST during broken channel operations was low: the craft bounced, heeling and hitting the ice pieces very hard at times.

PERSONNEL CARRYING

Although this prototype AST was not outfitted for carrying large numbers of passengers, or for allowing passengers much comfort, the value and ability of such a vehicle to do so was apparently great. On level ice the machine travels very smoothly despite there being no shock protection at all in the rotor support arrangements. Entry into open water or initial icebreaking is smooth and comfortable. Travel in previously broken ice can be quite rough, equivalent to stormy turbulence in a small aircraft. Continuous icebreaking is more comfortable and often involves only slightly more vibration than level ice travel.

Outfitted with padded and shock-absorbing seats and a suitable restraining safety system, the AST would perform very well as a passenger vehicle, able to travel over almost all Arctic marine terrain.

RESCUE CRAFT

Because the AST is amphibious it can access most marine situations in the Arctic and be available in all types of weather for rescue operations. For rescue purposes, higher speeds than those which the prototype AST-002 is capable of, are likely desirable, but such design changes are easily feasible. Accessories such as folding ladders and electric or hydraulic hoists would be applicable as well.

The high degree of control and the relative safety of rotors (rotation speeds of 60 RPM maximum) over screws add to the appeal of the AST for this application. Use of the AST design in open water with wave action would require some modifications to ensure stability and safety.

CARGO CARRYING

These tests provided some insights to the AST's capabilities for cargo carrying. The prototype tested was designed to carry only limited deck payload but was capable of one tonne ballast (water). By using an AST design with a large low profile and providing secure cargo hold downs, there is no reason why payloads of up to six tonnes or more could not be handled by such a craft.

4. CALCULATIONS

As demonstrated during the field trials, the AST's icebreaking capabilities can be enhanced by the use of several ice management techniques. One attractive scheme is to cut parallel slots in the ice, defining infinitely long cantilevers which the AST can then break into sections. This method has been modelled mathematically, based on the field observations. By varying items such as AST weight, ice flexural strength, ice thickness, and width of slot, matrices were produced, with each entry representing the length of the piece of ice which would fail. Induced moments are caluclated based on Hetenyi's beams on elastic foundation theories for end loading:

$$M = \frac{P}{\lambda} B_{\lambda x} \qquad (1)$$

where:
- M = induced moment
- P = weight of AST
- $1/\lambda$ = characteristic length of ice sheet (based on elastic modulus, see equasion #3)
- $B_{\lambda x} = e^{-\lambda x} \sin \lambda x$
- x = distance from free end of beam
- e = natural log

Tests were performed at Cargill's berth to estimate the characteristic lengths of the sheet. The method used was to cut beams of increasing width and of lengths longer than the expected failed beam by trenching parallel slots in the ice. The AST was then used to break the beams; length of failed beams increased as the beams got wider until the beam did not fail and the AST climbed out of the water. The longest beam failure recorded was 8.47 m. which typically represents 0.8 l_c. Hence the field estimated characteristic length of the sheet was 10.6 m., this ocrresponds with the empirical value of 10.9 m., using the following analysis for a plate on elastic foundation.

The other limit, maximum realistic width to be slotted, is set assuming slots more than $\frac{2}{\lambda_x}$ apart have virtually no effect and the cut out cantilever would actually behave more closely to an infinite sheet.

Table 1, shows such a matrix for the AST-002, under conditions close to those encountered during the Thunder Bay project. Ice thicknesses are shown along the matrix top and beam width down the left side. The first column indicates (-1.00) that slotting is assumed to be not required for this thickness at this ice strength. The remaining columns show the increasing broken beam lengths, until 0.00 is shown. After these points, the ice strengths are shown in Appendix D.

These values are useful in several ways. From them, for a given size of AST, continuous breaking of ice can be estimated as well as the ultimate breaking limit using slotting techniques. As well, different ice management procedures can be identified for clearing berths by obtaining the most practical width of slots to be cut.

$$\ell_c = \sqrt{\frac{D}{k}} \qquad (2)$$

where ℓ_c = characteristic length

$D = \frac{Eh^3}{12(1-\nu^2)}$

$k = \rho\omega g$

assuming $E = 8000\ \sigma_f$

σ_f = 850 kpa (evaluated from in situ small cantilever beam tests)

h = 0.6 m.

ν = 0.33

Hence ℓ_c = 10.9 m. with these figures.

From data this characteristic length for an ice sheet of different flexural strength can be estimated by:

$$\lambda \leq \sqrt[\gamma]{\frac{\max\ (FIELD)}{\max\ (ASSUMED)}}\ \lambda\ FIELD \qquad (3)$$

These values can then be used in the generation of the matrices. It must be emphasized that the calculations outlined are estimates only useful to produce a conservative evaluation of the AST's performance under varying conditions.

Bounds to the matrices have been approximated from observed ice behaviour in the field, although more definite limits could be set with the use of more complex analysis and algorythms. The two limits introduced are the maximum thickness for continuous failure of an infinite sheet and the maximum possible width of cantilever.

Thickness of maximum continuous breaking is set when a broken cantilever of 5.0 m. wide breaks at no more than $.20/\lambda_x$. Therefore, if for a 5.0 m. slot, the broken cantilever is less than $.20/\lambda_x$, continuous breaking is assumed possible, hence slotting is not required and -1.00 values are entered in the matrix for that particular ice thickness.

INPUT DATA:
SIGMA MAX = 700
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .117533672
CHARACTERISTIC LENGTH (1/LAMBDA) = 8.50820013
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	2.07	2.88	3.79	4.98	6.63	0.00	0.00	0.00
6.0	-1.00	2.52	3.43	4.70	6.36	0.00	0.00	0.00	0.00
7.0	-1.00	2.97	4.16	5.71	8.03	0.00	0.00	0.00	0.00
8.0	-1.00	3.43	4.79	6.83	0.00	0.00	0.00	0.00	0.00
9.0	-1.00	3.88	5.62	8.23	0.00	0.00	0.00	0.00	0.00
10.0	-1.00	4.34	6.45	0.00	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	4.88	7.37	0.00	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	5.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	6.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	7.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	8.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 1

CALCULATION MATRIX FOR

SIGMA = 700 KPa

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TABLE 2

AST FRESHWATER ICEBREAKING CAPABILITIES

ICE STRENGTH (KPa)	ICE THICKNESS (m)												
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3
500	U	U	U	U	U	U	A	A	A	A	A	A	X
550	U	U	U	U	U	U	A	A	A	A	A	X	X
600	U	U	U	U	U	A	A	A	A	A	A	X	X
650	U	U	U	U	U	A	A	A	A	A	A	X	X
700	U	U	U	U	U	A	A	A	A	A	A	X	X
750	U	U	U	U	U	A	A	A	A	A	X	X	X
800	U	U	U	U	U	A	A	A	A	A	X	X	X
850	U	U	U	U	U	A	A	A	A	A	X	X	X
900	U	U	U	U	A	A	A	A	A	X	X	X	X
950	U	U	U	U	A	A	A	A	A	X	X	X	X
1000	U	U	U	U	A	A	A	A	A	X	X	X	X

KEY

U = unassisted icebreaking

A = assisted icebreaking (with slotting)

X = unable to break ice

5. CONCLUSIONS

In general, the AST-002 performed very well during these tests and exceeded expectations for some aspects of the program, such as icebreaking.

The AST was found to be a safe and easily operated vehicle for heavy equipment activities such as pulling or pushing ice management accessories. There is no worry about the vehicle overturning or sinking. The craft is easily capable of operating large accessories, given properly designed tow linkages or connections. For convenient and efficient ploughing operations, the AST would best operate with a front mounted plough.

The AST-002 is capable of breaking fresh water ice over a range of thicknesses, in both assisted and unassisted modes. Table 2 indicates these ranges, the techniques required to achieve ice failure, and the calculated ice strength ranges associated with them. The AST concept can be extended with larger and/or heavier designs to increase the capabilities within these ranges.

The use of the AST for ice management plots preparation illustrated some of the aspects of using the craft as a tow or tug vehicle. The tests with the ACIB were not completed entirely, therefore conclusive evidence that the AST-002 is able to tow its own weight was not confirmed. However, there was no evidence from these tests to dispute the specified draw bar pull.

The AST-002 was shown by its speed, manoeuverability and amphibious capabilities to be well adapted for use as a personnel carrier, a rescue craft or a cargo carrier. The use of specific accessories for some of these purposes is indicated, but there would be no difficulty adjusting the AST concept for these purposes.

From these conclusions, recommendations for an AST design suitable for the Port of Thunder Bay are derived.

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For the scope of work application of an AST at Thunder Bay, a craft with a displacement of 24.5 tonnes and a power rating of 525 kW would be capable of icebreaking up to 0.9m thickness at rates of 1.6m to 2.0m/sec. Such a machine would clear out the ship berths quite easily and be very useful in re-breaking ship tracks and keeping them clear (Arctec Canada, 1982). A machine of this size would handle all but the most severe ice conditions expected at Thunder Bay and extended techniques could be applied for those. In addition, such a craft could support regular icebreaking operations to a high degree.

Similarly, recommendations about designs for other locations, such as in the Arctic, could be given with information about expected ice properties and conditions.

6. REFERENCES

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APPENDIX A

THUNDER BAY FIELD TRIP

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THUNDER BAY FIELD TRIP

THURSDAY, 11 MARCH 82:

Kevin Butt, Jason Edworthy and Dusty Miller arrived at Thunder Bay.

FRIDAY, 12 MARCH 82:

The AST was released from Customs and moved to Keefer Terminal.

D. Miller, J. Edworthy, and K. Butt visited Richard Kamo at V.B. Cook to discuss our program schedule. V.B. Cook would be monitoring the ice thickness at the Cargill Ship.

K. Butt and J. Edworthy visited Bob Miller (operations manager of Cargill terminal) and discussed their tests with him.

D. Miller visited Canadian Coast Guard Base. Spoke with Geo Steigh, Position and Capt. J. McDonald and Chief Engineer Bob Williams, both of the CCGS Alexander Henry. D. Miller reviewed with them our program, and the craft and its capabilities. It was decided that the area straight off the Keefer terminal towards the breakwater would be a good site for ice management studies since the CCGS Alexander Henry's normal operations do not enter this area, due to draft restrictions (Figure 2, test).

D. Miller and Geo Steigh visited Lakehead Harbour Commission. Saw Phil McLeod (Supt. Maintenance), Dick Legras (Harbour Master) and Capt. Al Brown (asst. Harbour Master). D. Miller discussed with them the program, and the AST and its capabilities.

D. Miller met with Mr. Les Willis, - Sr. Surveyor of the Canadian Coast Guard. D. Miller was told that the AST does not require an inspection being below the required tonnage but should have life jackets, navigation lights and a fire extinguisher aboard.

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SATURDAY, 13 MARCH 82:

K. Butt, J. Edworthy and D. Miller went for supplies to build cribs to accomodate AST hull during construction. Two cribs were built about 0.9m x 0.9m x 0.9m. Construction was of 100mm x 100mm rough lumber spiked together (see sketch or photo). A crane unloaded the AST from the railcar. Assembly of the AST began. K. Butt observed AST construction.

J. Edworthy and D. Miller went onto ice to survey plots involved with ice management (Figure 3, text).

K. Butt, J. Edworthy and D. Miller constructed sled for scarifying (Figure 5, text).

SUNDAY, 14 MARCH 82:

D. Miller left Thunder Bay for Calgary.

K. Butt made field sketch of sled.

J. Edworthy had a discussion with Mr. Komoto regarding AST disposition.

K. Butt and J. Edworthy finished surveying plots out on the ice. Measurements were taken of ice thickness by drilling.

MONDAY, 15 MARCH 82:

K. Butt obtained diesel fuel for AST.

J. Edworthy and K. Butt obtained components necessary for plough construction. J. Edworthy and K. Butt then assisted in placing the AST via crane onto the ice. Rode as passengers on the AST to show the ice management site to the Japanese. Arranged AST night parking with Jim Hill. Acquired a portable radio for the AST from Mr. Zaharak of security. The plough was completed and attached to the AST by chains. Empty oil drums were obtained to hold water as weight for the plough and the scarifier.

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TUESDAY, 16 MARCH 82:

Ploughing operations were started and by the end of the day, half of the ploughing had been completed. The AST pulled the plough at about 1½ - 2 kmph. Mr. P.R. Cook, Lakehead Harbour Commission, and Jim Hill, Port Manager, were taken for a ride. Part of the ride took place at slip 7A at Jim Hill's request.

WEDNESDAY, 17 MARCH 82:

D. Miller left Calgary for Thunder Bay.

A. Haller, J. Owler Petro-Canada (A.P.P.) and P. Nungaq of Resolute Hunters and Trappers Association arrived in Thunder Bay.

J. Edworthy and D. Miller had a discussion with Haller, Owler and Komoto regarding Petro-Can's needs with regards to an AST and tomorrows trial program.

K. Butt worked on engineering drawing of sled.

THURSDAY, 18 MARCH 82:

J. Edworthy and D. Miller befan ploughing and drilling holes for ice thickness tests. At 10:30 ploughing ceased and J.E. and D.M. drove to Keefer to meet Jim Owler, P. Nungaq and Al Haller. The AST did several ship track crossings of previously broken outbound track by CCGS Alexander Henry from C.C.G. base. Some time was spent examining the ship track characteristics. D. Miller, Haller and Nungaq crossed it on foot. The AST was then driven to Cargill with Miller, Haller, Owler, and Nungaq on board.

K. Butt drilled ice thickness holes in plots. Depth: A1 77.7cm, A2-77.7cm, A3-72.4cm, A4-82.3cm, B1-96.8cm, B2-89.2cm, B3-68.6cm, C1-91.4cm, C2-87.7cm, C3-68.6cm, C4-82.3cm, D1-70.1cm, D2-89.9cm, D3-98.3cm, and D4-94.5cm.

D. Miller (when returning from the Cargill slip to Keefer) at an open water near ductfall of Ontario Hydro power plant, noted that the AST broke through ice on approach about 40m short of open water edge - ice thickness was approximately 23cm. Once across the water the AST broke through for about 30m where the ice thickness was approximately 23cm.

En route to Keefer near the end of breakwater the craft broke through the ice cover for about 30m. The ice was relatively thin 40 - 50cm, probably due to current around the water end - thickness increased rapidly away from this local area and no other ice was broken here.

D. Miller, K. Butt and J. Edworthy engaged in scarifying - craft moved N-S covering plots A and B. The 'D' row of the plots was then dusted with grain dust.

FRIDAY, 19 MARCH 82:

K. Butt left for Calgary.

Because of cold overnight temperatures the melt water from the day before had frozen solid on the surface of the ice forming a bond between the AST rotors and the intact ice surface. The craft did not help and eventually local contractors with a fork lift truck jerked the craft loose. In future some provision will be needed to avoid this problem. Ideas are a power jack at one corner - heat in the rotors - more torque - care where parking is done.

J. Edworthy and D. Miller observed snow at plots. The snow piled by the scarifier caught blowing snow but the grooves did not seem to fill up. In scarified areas the snow was very had. The control area had a light crust and the snow was stiff but not hard. The dusted area had holes up to 3.8cm deep where snow had melted or sublimated, leaving snow a rough cratered surface which was generally soft and spring-like. The albedo was obviously lower to the eye. The areas that were dusted nearly continuously but not thickly were the best this day. Snow depths were taken in the unploughed plots.

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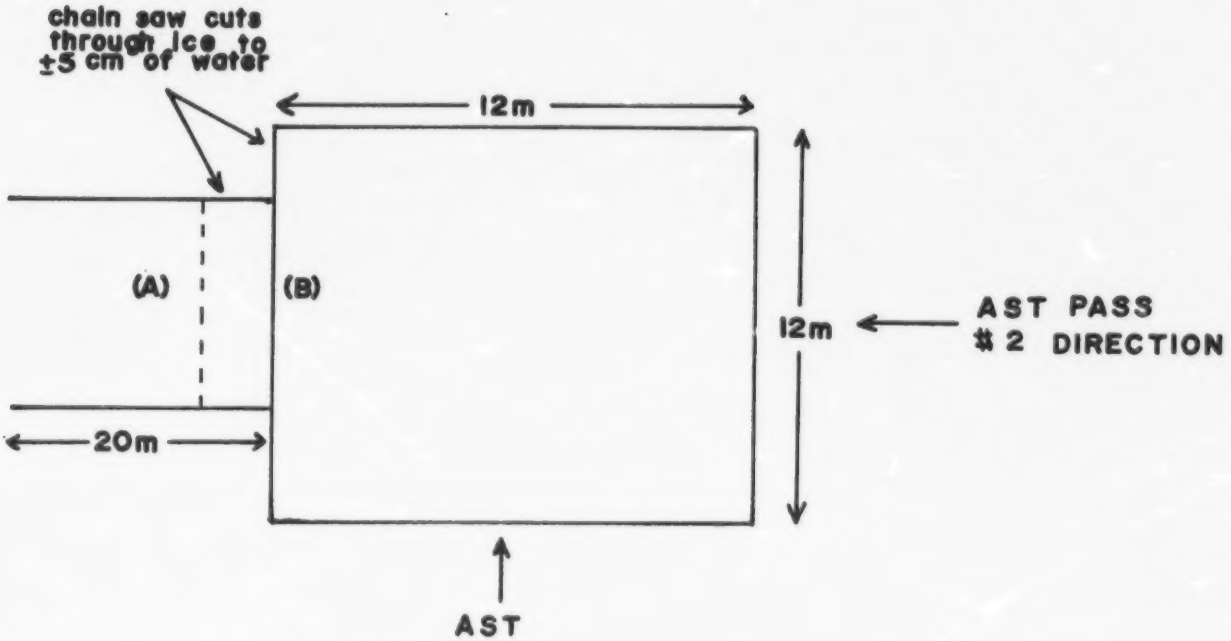
D. Miller and J. Edworthy went out on the ice just to the North of the plots and cut an area as shown below, in an attempt to open an area of ice with the AST.



Pass 1 - no movement any place (toward breakwater).

Pass 1 - reverse, no movement.

Pass 2 - no movement (to north) cut (A) then deepened with long saw to 30cm.

Pass 2 - again no movement. Craft turned around, again no movement. Craft stopped on piece, no movement. Craft backed up. Cleared slots again under one rotor (cuts (A) and (B)). Still no observable movement. Attempt made to cut ice block out but area flooded. Ice cover 90cm thick at this place.

Conclusion: The shear strength of even 2cm of ice at the bottom of a slot will exceed the weight of the craft.

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SATURDAY, 20 MARCH 82:

J. Edworthy discussed with Jack Lafromboise AST involvement with the ACIB, as a tow vehicle and as a manoeuverable anchor. During a talk with Jim Hill, he confirmed that the press day is still scheduled for March 24.

Jason and Dusty altered the scarifier by changing the number of spacer nuts from two to five, changing the tooth length from 9cm to 33cm.

Dusty left Thunder Bay for Calgary.

Jason finished sled and took more photographs of the AST. The plough was brought into Keefer this day and it was arranged to use the scarifier Sunday afternoon.

SUNDAY, 21 MARCH 82:

Jason conducted scarifying. The longer bolts seem to work much better in the snow. The troughs were deep and clean and the sled tracked very well. However, on ice it seemed to judder and shake much more and acutally missed gouging. There were eight lanes in row A. To re-do it with the longer protruding bolts it took less than an hour operating time because of acquired skills and existing windrows which guide the driver and sled. The sled was loaded with three half full 45 gallon drums, each weighing approximately 100 kg. The driver was getting very skilled at manoeuvering the vehicle with a sled load.

After bringing in the scarifier, the AST was driven out to the end of the E-W breakwater, at the mouth of the Kam Kam River. There filming was done of breaking ice 40 - 50cm thick. The top 15cm of the ice was white ice. The ice broke quite easily.

L. Chabot arrived in Thunder Bay from Calgary.

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MONDAY, 22 MARCH 82:

L. Chabot, and J. Edworthy began experiments at Cargill. The trencher was placed onto the ice and a 6m x 6m plot was cut up. (Figure 26, text).

The AST was driven across the plot. It displaced the ice without difficulty and broke the three end cantilevers.

Option 1 - A shallow 30cm slot was cut 2m ahead of the hole parallel to it, using the chain saw. The AST was driven over it with no success. It was therefore deepened to 45cm.

Option 1-1 - Deeper than above - not working, no effect.

Option 1-2 - Cut to water in this slot. This had no apparent effect either. An observation made during those attempts was that troughs were cut into the ice by the rotors (Figure 26, text).

Option 2 - Parallel, double slots (Figure 27, text).

The beam broke just past the slots for a total beam length of 8.6m.

Option 2-1 - Longer slots as above (20m long). The ice broke easily, in 3 places (Figure 27, text).

Option 3 - a technique used to 'chip away' a hole using 'V' shaped cuts i.e. "chevrons". This technique broke less ice but into much smaller pieces. The technique was not as efficient for ice breaking since less ice was broken for similar amounts of cutting (Figure 28, text).

Took B. Miller (Cargill) for a ride on AST; broke 2 hectares of ice at Hydro site on Mission River.

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TUESDAY, 23 MARCH 82:

L. Chabot and J. Edworthy obtained more grain dust and spread it over row 'D'. The plough was disassembled and the blade was returned. In the afternoon filming of icebreaking was done off Cargill berth. The AST broke 50-70cm thick ice, broke approximately 2 hectares in less than one hour for a total of 4 hectares. The AST tried floe pushing. At slow speed it cleared a very good channel espceially with large ice pieces. It pushed easily for 90m and the channel stayed cleared behind. The AST was then driven along the ice edge to weaken the ice, then driven back perpendicular to the edge to break it. This extended the craft's capabilities past the limits for regular breaking.

Peter Noble and Deb Dumka arrived.

Informal discussion with Task Force members was held in the evening.

WEDNESDAY, 24 MARCH 82:

Luc cut two chainsaw slots 20m long, 6m apart, leading from the Alexander Henry ship track at Keefer, for an icebreaking demonstration for the Task Force presentation.

AST performed level ice, broken channel and icebreaking demonstrations for members of the Task Force and media. Several trips were made with Task Force members aboard.

Peter Noble met with Task Force and media at press conference.

P. Noble, J. Edworthy met with A. Gagnon (M.O.T.) and L. McCoomb (TDC) at lunch, discussing size and type of AST suitable for harbor ice management.

Luc arranged for AST to break ice off shore from the Ontario Hydro Thermal Plant.

In afternoon, P. Noble, J. Edworthy, L. Chabot with A. Gagnon and L. McCoomb viewed AST breaking up to 60cm of ice off the Hydro Plant at the

mouth of the Mission River. Ice was also broken along the Hydro Plant wharf.

L. McCoomb and A. Gagnon asked that Arctec continue monitoring the ice management plots for an additional period of time.

P. Noble left Thunder Bay.

THURSDAY, 25 MARCH 82:

Luc and Jason continued experiments at Cargill Slips using a Ditchwitch trenching machine. Luc supervised cutting of slots for additional icebreaking and ice beam tests for strength properties. The Ditchwitch trencher is capable of 1.5m/min. cutting through to water (approx. 80cm) and 3m/min. cutting to 50cm depth. This is not the full capacity of the machine since the cutting chain used is not as efficient as it could be. We note that a chain with cutting "knobs" instead of blades would likely be better.

1. The cutting patterns conducted are shown in Figure 29 in the text. The first cut similar to previous parallel slots broke at about 8.5m.

2. The wider beam (10m) did not fail immediately but after four passes of the AST the ice broke in a "random" pattern of approximately six to seven irregular pieces, bounded by the saw cuts.

3. A wider beam yet (15m) did not fail at all.

4. The AST was used to fatigue the ice edge along the previously broken slotted areas, then driven into the broken ice and up the fatigued edge. Considerable failure and breaking was observed of ice up to 81cm thick.

L. Chabot, R. Abdenlnour left Thunder Bay.

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L. Chabot, R. Abdelnour and J. Edworthy cut beams and broke them for strength:

$$\sigma = \frac{6\,P\ell}{bh^2}$$

where b is breadth of beam
h is thickness of beam
ℓ is length of beam
P is applied load (measured/with lever calculations)
σ is flexural strength

Beam #1 b = .69 m
h = .74 m
ℓ = 2.16 m
P = 17062.50 N/ 19587.75
σ = 676.83 KPa

Beam #2 b = .81 m
h = .74 m
ℓ = 3.15 m
P = 17344.6 N/ 23414.30 N
σ = 995.82 KPa

Beam #3 b = .97 m
h = .74 m
ℓ = 5.18 m
P = 11206.65 N/ 12066.60
σ = 710.99

SURFACE TEMPERATURE OF ICE = -1.2°C

ARCTEC CANADA LIMITED

FRIDAY, 26 MARCH 82:

Jason sorted and temporarily stored field equipment. Canada Steamship Lines contacted re cutting out the Frontenac. Contacted J. Laframboise re ACIB readiness for the next week.

J. Edworthy left Thunder Bay.

SATURDAY, 27 MARCH 82:

No activity (days off).

SUNDAY, 28 MARCH 82:

No activity (days off).

MONDAY, 29 MARCH 82:

George Comfort arrived in Thunder Bay.

George and Deb measured ice thicknesses, snow depths, measured snow density, took photographs at plots.

TUESDAY, 30 MARCH 82:

George and Deb measured ice thicknesses and took photographs.

Jason contacted Canada Steamship Lines again, received negative response re CSL participation in cutting Frontenac out. CSL does not mind if Arctec goes ahead.

WEDNESDAY, 31 MARCH 82:

Jason arrived in Thunder Bay.

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THURSDAY, 1 APRIL 82:

Jason and George met with J. Laframboise in morning at shipyard.

Jason contacted T. Powell of City of Thunder Bay to arrange AST trial on Neebing River, which had been dynamited to speed up ice breakup for flood prevention. The ice thickness varied from 30cm to 90cm. The river is shallow and in many places the ice was grounded.

Jason and George filmed AST breaking up Neebing River where it was dynamited. Also measured ice thicknesses and took photographs of plots.

George left Thunder Bay.

FRIDAY, 2 APRIL 82:

Jason met with V.B. Cook engineers to go over their role as independent observers.

Jason and Deb arranged monthly weather information acquisition. Photographed plots (oblique only, several only), photographed bubbler systems at Sask Pool site and Cargill slip area. The local weather was deteriorating into heavy snow with some sleet and high winds.

SATURDAY, 3 APRIL 82:

Jason and Deb monitored plots - no measurements or photographs taken due to high winds and poor visibility.

SUNDAY, 4 APRIL 82:

Jason and Deb met with J. Laframboise to discuss ACIB trials with AST. Measured ice thicknesses, snow depths at plots, took photographs at plots. There were no visual changes in the plots during the storm, except some accumulation of drifted snow.

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MONDAY, 5 APRIL 82:

Jason contacted Jim Hill about temporary storage of the AST. Dismantled scarifier. Took general photos only of experimental plots as cold weather was preventing visible changes of ice. The dusted areas of the plots seem to be less solidly frozen than the others, and crackled slightly under body weight.

TUESDAY, 6 APRIL 82:

Jason tentatively arranged temporary storage and later transportation of AST. Supported ACIB transit from grounded storage site to dockside at Port Arthur Shipyard with AST. No visit to plots.

WEDNESDAY, 7 APRIL 82:

Jason confirmed AST temporary storage. Jason and Deb removed remaining materials at Keefer, arranged storage of additional equipment. Jason left Thunder Bay, and Deb took photographs of plots.

APRIL 8 to APRIL 30:

Photographs and film processed. Data analysis, film production and reporting begins.

MAY 3 to MAY 5:

J. Edworthy and S. Bourne arrive at Thunder Bay and dismantle AST for shipment to United States.

MAY 5 to MAY 30:

AST travels by rail to Moses Lake, Washington.

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APPENDIX B

OPERATIONS TIMES

OPERATIONS EFFECTIVENESS

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AST OPERATIONS EFFECTIVENESS

ICEBREAKING

1. Refrozen ship tracks (previously broken ice)

speed = 3 knots (1.17 m/sec) maximum)
effective breaking width - 10 m
rate = 42,000 m^2/hr capability
4.2 hectares/hr capability, maximum

Effectively the rate will be somewhate greater than this, because adjacent passes could be separated by an additional 5m and provide the same effectiveness.

rate = 4.2 hectares/hr capability, with separation

2. Level icebreaking

ice thickness = up to 45 cm
speed = 3 knots (1.17 m/sec) maximum
effective breaking width = 7 m
separation of passes = 5 m
rate = 2.9 hectares/hr, no separation
= 4.0 hectares/hr, with separation

3. Level icebreaking

ice thickness = 45 to 60 cm
speed = .5 knots (.195 m/sec) maximum
effective breaking width = 8 m
separation = 5 m
rate = .56 hectares/hr, no separation
= .74 hectares/hr, with separation

4. Level icebreaking

ice thickness = 60 cm + (using slotting)
speed = .065 knots (.025 m/sec) maximum
effective breaking width = 8 m
separation = 0 m
rate = 0.72 hectares/hr

TRAVEL

1. Level ice travel

speed = 6 knots (2.34 m/sec) maximum

2. Broken ice travel

speed = 3 knots (1.17 m/sec) maximum

3. Open water travel

speed = 3 knots (1.17 m/sec) maximum

ARCTEC CANADA LIMITED

ESTIMATED AST MAINTENANCE AND DOWN TIMES

Minor Servicing

Approximately two hours per week

Major Servicing

Approximately eight hours per 2500 hours service

Overhauls, Repairs

Approximately 16 hours per 5000 hours service. It is estimated that the main rotor bearings would need servicing and possible replacement at this time. Also, rotor surfaces would likely require repairs or complete replacement.

ARCTEC CANADA LIMITED

APPENDIX C

WEATHER INFORMATION

Environment Canada / Environnement Canada

Atmospheric Environment Service / Service de l'environnement atmosphérique

MONTHLY METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE MENSUEL

MONTH/MOIS MARCH / MARS 1982

AT/À THUNDER BAY "A", ONTARIO

LAT 48° 22' N LONG 89° 19' W ELEVATION: ALTITUDE: 199 METRES (ASL) MÈTRES (NMM) STANDARD TIME USED: HEURE NORMALE UTILISÉE: EASTERN EST

DATE	TEMPERATURE TEMPÉRATURE			DEGREE-DAYS DEGRÉS-JOURS		REL. HUMIDITY HUMIDITÉ REL.		THUNDERSTORM ORAGE	PRECIPITATION PRÉCIPITATIONS			SNOW ON GROUND NEIGE AU SOL	WIND VENT			BRIGHT SUNSHINE INSOLATION EFFECTIVE
	MAXIMUM MAXIMALE °C	MINIMUM MINIMALE °C	MEAN MOYENNE °C	HEATING DE CHAUFFE BASE 18.0°C	GROWING DE CROISSANCE BASE 5.0°C	MAXIMUM MAXIMALE %	MINIMUM MINIMALE %		RAINFALL PLUIE (HAUTEUR) mm	SNOWFALL NEIGE (HAUTEUR) cm	TOTAL PRECIP. PRÉCIP. TOTALE mm	cm	AVERAGE SPEED VITESSE MOYENNE km/h	PREVAILING DIRECTION DIRECTION DOMINANTE	MAXIMUM SPEED AND DIRECTION VITESSE MAXIMALE ET DIRECTION km/h	HOURS HEURES
1	-3.3	-12.8	-8.1	26.1		73	57			0.2	0.2	26	30.0	W	WNW 43	7.9
2	-8.3	-19.8	-14.1	32.1		72	29					26	14.2	NW	NW 22	9.6
3	-8.3	-26.4	-17.4	35.4		85	37					26	7.4	SW	WSW 15	4.2
4	-1.6	-21.9	-11.8	29.8		73	36			TR	TR	26	10.8	WSW	SVRL 22	5.3
5	-5.7	-17.4	-11.6	29.6		78	35					26	17.1	SVRL	W 30	9.2
6	-5.7	-18.1	-11.9	29.9		62	30			TR	TR	26	18.3	WSW	NW 28	7.7
7	-10.6	-24.4	-17.5	35.5		59	30					26	9.1	SVRL	WNW 19	9.6
8	-11.4	-28.4	-19.9	37.9		92	39			0.3	0.2	26	7.3	W	E 15	1.4
9	-7.1	-26.9	-17.0	35.0		92	40			0.4	0.2	26	9.5	SW	S 20	6.9
10	-3.1	-9.6	-6.4	24.4		93	68			10.0	9.6	26	13.0	SVRL	SVRL 19	0.0
11	-0.9	-13.4	-7.2	25.2		92	54			TR	TR	36	10.9	WNW	NW 19	6.7
12	2.3	-12.8	-5.3	23.3		100	75		16.2	1.5	17.7	35	15.6	SVRL	ENE 30	2.8
13	2.3	-4.3	-1.0	19.0		87	63			TR	TR	28	34.9	W	W 57	1.5
14	3.9	-9.1	-2.6	20.6		86	30					28	18.3	W	W 44	9.7
15	3.3	-3.0	0.2	17.8		86	52					28	14.8	E	E 28	5.7
16	1.5	-1.4	0.1	17.9		93	64			1.6	1.3	28	15.0	E	SVRL 24	0.0
17	2.6	-0.3	1.2	16.8		86	60			TR	TR	28	6.3	E	E 15	0.1
18	2.2	-9.6	-3.7	21.7		93	58			5.4	5.2	33	11.2	NNW	NNE 26	2.6
19	-2.1	-14.8	-8.5	26.5		85	39					32	10.3	E	E 19	10.0
20	-1.1	-8.5	-4.8	22.8		86	37			0.4	0.4	32	18.5	ENE	SVRL 26	2.2
21	6.6	-4.0	1.3	16.7		93	28			1.2	1.0	33	13.6	W	WNW 26	6.3
22	4.3	-6.7	-1.2	19.2		86	35					32	12.1	WNW	SSW 22	10.1
23	5.2	-8.5	-1.7	19.7		100	56					31	7.8	NE	SW 20	4.9
24	3.2	-1.8	0.7	17.3		100	74		0.2	4.6	4.4	32	17.5	W	SVRL 30	0.4
25	-1.6	-12.1	-6.9	24.9		86	53			0.5	0.3	35	14.6	N	N 26	0.6
26	-5.5	-16.6	-11.1	29.1		78	32					35	12.9	SVRL	N 26	9.9
27	-4.0	-19.0	-11.5	29.5		92	25					35	6.6	SSE	SSW 19	10.7
28	5.0	-16.3	-5.7	23.7		92	48					35	11.6	SW	SW 30	0.0
29	5.7	0.7	3.2	14.8		93	52		0.4	TR	0.4	34	9.7	ENE	ENE 17	0.0
30	3.3	0.9	2.1	15.9		100	87		22.9	TR	22.9	32	17.7	E	ENE 26	0.0
31	5.0	-3.3	0.9	17.1		100	45		1.0	TR	1.0	24	27.3	W	W 49	1.1
MEAN MOYENNE	-0.8	-11.9	-6.4	TOTAL 755.2	TOTAL	87	47	TOTAL 0	TOTAL 40.7	TOTAL 26.1	TOTAL 64.8		14.3	PREVAILING W	MAXIMUM W 57	TOTAL 147.1
NORMAL NORMALE	0.0	-12.3	-6.2	749.4				0	10.4	35.3	43.7		14.3	W		185.2

DEGREE-DAY SUMMARY – SOMMAIRE DE DEGRÉS-JOURS

BELOW 18°C AU-DESSOUS DE 18°C	THIS YEAR ANNÉE EN COURS	PREVIOUS YEAR ANNÉE PRÉCÉDENTE	NORMAL NORMALE	ABOVE 5°C AU-DESSUS DE 5°C	THIS YEAR ANNÉE EN COURS	PREVIOUS YEAR ANNÉE PRÉCÉDENTE	NORMAL NORMALE
TOTAL FOR MONTH TOTAL DU MOIS	755.2	639.0	749.4	TOTAL FOR MONTH TOTAL DU MOIS			
ACCUMULATED SINCE JULY 1 ACCUMULÉE DEPUIS LE 1er JUILLET	4977.7	4748.7	4843.1	ACCUMULATED SINCE APRIL 1 ACCUMULÉE DEPUIS LE 1er AVRIL			

DAYS WITH TOTAL PRECIPITATION: JOURS AVEC PRÉCIPITATIONS TOTALES: mm

0.2 OR MORE – OU PLUS	1.0 OR MORE – OU PLUS	2.0 OR MORE – OU PLUS	10.0 OR MORE – OU PLUS	50.0 OR MORE – OU PLUS
14	8	5	2	0

DAYS WITH SNOWFALL: JOURS AVEC CHÛTE DE NEIGE: cm

0.2 OR MORE – OU PLUS	1.0 OR MORE – OU PLUS	3.0 OR MORE – OU PLUS	10.0 OR MORE – OU PLUS	50.0 OR MORE – OU PLUS
11	6	3	1	0

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Canada

Environment Canada / Environnement Canada

Atmospheric Environment Service / Service de l'environnement atmosphérique

MONTHLY METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE MENSUEL

MONTH/MOIS APRIL / AVRIL 19 82

AT/À THUNDER BAY "A" ONTARIO

LAT 48 ° 22 'N LONG 89° 19 'W ELEVATION/ALTITUDE: 199 METRES (ASL) METRES (NMM) STANDARD TIME USED/HEURE NORMALE UTILISÉE: EASTERN EST

DATE	TEMPERATURE TEMPÉRATURE			DEGREE-DAYS DEGRÉS-JOURS		REL. HUMIDITY HUMIDITÉ REL		THUNDERSTORM ORAGE	PRECIPITATION PRÉCIPITATIONS			SNOW ON GROUND NEIGE AU SOL	WIND VENT			BRIGHT SUNSHINE INSOLATION EFFECTIVE
	MAXIMUM MAXIMALE	MINIMUM MINIMALE	MEAN MOYENNE	HEATING DE CHAUFFE	GROWING DE CROISSANCE	MAXIMUM MAXIMALE	MINIMUM MINIMALE		RAINFALL PLUIE (HAUTEUR)	SNOWFALL NEIGE (HAUTEUR)	TOTAL PRECIP PRÉCIP TOTALE		AVERAGE SPEED VITESSE MOYENNE	PREVAILING DIRECTION DIRECTION DOMINANTE	MAXIMUM SPEED AND DIRECTION VITESSE MAXIMALE ET DIRECTION	
	°C	°C	°C	BASE 18.0°C	BASE 5.0°C	%	%		mm	cm	mm	cm	km/h		km/h	HOURS HEURES
1	2.3	-10.8	-4.3	22.3		74	34			TR	TR	23	23.0	WNW	NW 50	10.8
2	-0.1	-4.0	-2.1	20.1		93	58		5.3	4.0	14.1	23	32.8	E	E 43	0.0
3	0.2	-14.4	-7.1	25.1		93	72		3.6	8.8	12.0	26	26.3	NNW	N 41	0.0
4	-4.3	-14.5	-9.4	27.4		72	38			0.4	0.2	34	21.5	NW	NNW 33	8.8
5	-4.0	-20.5	-12.3	30.3		77	32					34	10.7	SVRL	S 19	10.5
6	-1.2	-17.7	-9.5	27.5		85	23					33	8.5	WNW	SVRL 17	10.6
7	2.2	-19.4	-8.6	26.6		92	27					32	10.3	WSW	SSE 26	12.0
8	5.2	-13.4	-4.1	22.1		85	28					31	9.1	W	S 24	12.3
9	5.5	-4.4	0.6	17.4		86	41					30	9.4	SW	W 17	6.6
10	4.5	-2.0	1.3	16.7		93	60			0.4	0.4	25	5.2	E	SW 13	4.4
11	4.8	-2.9	1.0	17.0		93	52					22	12.1	WSW	SSE 24	7.4
12	3.2	-1.7	0.8	17.2		93	65		1.4	2.0	3.4	20	12.5	E	E 20	0.0
13	10.7	-1.0	4.9	13.1		93	36					19	16.3	NNW	NNW 33	8.3
14	8.8	-2.2	3.3	14.7		93	53					14	12.3	E	SVRL 19	5.5
15	13.3	0.5	6.9	11.1		100	62		5.3		5.3	12	12.7	E	SSW 26	2.2
16	9.0	2.4	5.7	12.3		93	76		6.3		6.3	4	8.4	NNW	SVRL 20	0.0
17	2.4	-1.5	0.5	17.5		80	51			0.3	0.3	3	25.6	NW	NNW 39	0.2
18	4.8	-5.8	-0.5	18.5		79	44					3	12.0	E	SVRL 22	10.0
19	4.5	-4.1	0.2	17.8		74	26					2	14.3	NNE	SVRL 24	12.6
20	4.0	-5.7	-0.9	18.9		50	23					1	20.1	N	SVRL 28	10.6
21	10.5	-8.0	1.3	16.7		80	18					TR	14.3	SW	WNW 30	13.5
22	16.1	-4.6	5.8	12.2		86	25					TR	19.5	WSW	W 37	13.5
23	25.7	0.2	13.0	5.0		75	17					TR	19.0	WSW	SW 32	13.0
24	25.0	-1.4	11.8	6.2		87	24					0	19.6	E	SSW 41	13.5
25	17.5	2.1	9.8	8.2		81	36					0	17.0	NNW	SVRL 37	11.0
26	9.4	-3.1	3.2	14.8		74	27					0	12.9	NNE	N 22	12.8
27	11.1	-3.5	3.8	14.2		86	29					0	9.3	S	SVRL 22	13.5
28	18.3	-4.9	6.7	11.3		86	20					0	12.3	SVRL	S 33	13.9
29	18.0	-3.4	7.3	10.7		93	16					0	12.8	E	SVRL 26	13.7
30	13.3	-3.5	4.9	13.1		86	38					0	9.7	E	SVRL 20	4.0
				TOTAL	TOTAL			TOTAL	TOTAL	TOTAL	TOTAL			PREVAILING	MAXIMUM	TOTAL
MEAN MOYENNE	8.0	-5.7	1.2	506.0		84	38	0	21.9	15.9	42.0		14.3	E	NW 50	255.2
NORMAL NORMALE	8.1	-3.4	2.4	469.3				1	36.6	20.1	56.4		15.9	E		205.4

DEGREE-DAY SUMMARY – SOMMAIRE DE DEGRÉS-JOURS

BELOW 18°C AU-DESSOUS DE 18°C	THIS YEAR ANNÉE EN COURS	PREVIOUS YEAR ANNÉE PRÉCÉDENTE	NORMAL NORMALE	ABOVE 5°C AU-DESSUS DE 5°C	THIS YEAR ANNÉE EN COURS	PREVIOUS YEAR ANNÉE PRÉCÉDENTE	NORMAL NORMALE
TOTAL FOR MONTH TOTAL DU MOIS	506.0	438.3	469.3	TOTAL FOR MONTH TOTAL DU MOIS			
ACCUMULATED SINCE JULY 1 ACCUMULÉE DEPUIS LE 1er JUILLET	5483.7	5187.0	5312.4	ACCUMULATED SINCE APRIL 1 ACCUMULÉE DEPUIS LE 1er AVRIL			

DAYS WITH TOTAL PRECIPITATION JOURS AVEC PRÉCIPITATIONS TOTALES: mm

0.2 OR MORE – OU PLUS	1.0 OR MORE – OU PLUS	2.0 OR MORE – OU PLUS	10.0 OR MORE – OU PLUS	50.0 OR MORE – OU PLUS
8	5	5	2	0

DAYS WITH SNOWFALL: JOURS AVEC CHÛTE DE NEIGE: cm

0.2 OR MORE – OU PLUS	1.0 OR MORE – OU PLUS	2.0 OR MORE – OU PLUS	10.0 OR MORE – OU PLUS	50.0 OR MORE – OU PLUS
6	3	3	0	0

UDC 551.506.1 : 713.12

Subscription Price: $1.00 monthly, $10.00 per calendar year (January to December)
Prix d'abonnement: mensuel $1.00, annuel $10.00 (janvier à décembre)

Canada

APPENDIX D

ICEBREAKING CALCULATIONS

ARCTEC CANADA LIMITED

ICEBREAKING CALCULATIONS

In the tables which follow, input data are listed on the top. The top row of the matrix shows ice thickness categories from .5m to 1.3m. The left most column shows beam widths from 5m to 17m. The contents of the matrices indicate the length of beam which is estimated to break at the input ice strength and vehicle weight. Where -1.00 values are shown, it is estimated that the craft will continuously break that thickness of ice, as an infinite sheet. Where 0.00 values are shown, it is calculated that even with slotting techniques, the craft will no longer be able to break this ice.

The input data includes SIGMA MAX, which is the assumed ice flexural strength in KPa. LAMBDA and 1/LAMBDA are characteristic length parameters, derived from the measured elastic modulus.

INPUT DATA:
SIGMA MAX = 500
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .12784811
CHARACTERISTIC LENGTH (1/LAMBDA) = 7.82178166
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	-1.00	2.07	2.70	3.43	4.43	5.62	7.28	0.00
6.0	-1.00	-1.00	2.43	3.25	4.25	5.53	7.46	0.00	0.00
7.0	-1.00	-1.00	2.88	3.88	5.17	7.01	0.00	0.00	0.00
8.0	-1.00	-1.00	3.34	4.52	6.18	0.00	0.00	0.00	0.00
9.0	-1.00	-1.00	3.79	5.26	7.46	0.00	0.00	0.00	0.00
10.0	-1.00	-1.00	4.34	6.09	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	-1.00	4.88	7.01	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	-1.00	5.44	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	-1.00	6.09	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	-1.00	6.73	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	-1.00	7.56	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 550
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .12483781
CHARACTERISTIC LENGTH (1/LAMBDA) = 8.01039367
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	-1.00	2.25	2.97	3.88	4.98	6.36	0.00	0.00
6.0	-1.00	-1.00	2.70	3.61	4.79	6.27	0.00	0.00	0.00
7.0	-1.00	-1.00	3.15	4.34	5.81	0.00	0.00	0.00	0.00
8.0	-1.00	-1.00	3.70	5.08	7.01	0.00	0.00	0.00	0.00
9.0	-1.00	-1.00	4.25	5.91	0.00	0.00	0.00	0.00	0.00
10.0	-1.00	-1.00	4.79	6.92	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	-1.00	5.44	0.00	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	-1.00	6.09	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	-1.00	6.83	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	-1.00	7.75	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 600
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .122151555
CHARACTERISTIC LENGTH (1/LAMBDA) = 8.18655153
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	1.78	2.43	3.25	4.25	5.44	7.10	0.00	0.00
6.0	-1.00	2.16	2.97	3.97	5.26	7.01	0.00	0.00	0.00
7.0	-1.00	2.52	3.52	4.79	6.45	0.00	0.00	0.00	0.00
8.0	-1.00	2.88	4.07	5.62	8.03	0.00	0.00	0.00	0.00
9.0	-1.00	3.25	4.70	6.63	0.00	0.00	0.00	0.00	0.00
10.0	-1.00	3.70	5.35	7.84	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	4.07	6.00	0.00	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	4.52	6.83	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	4.98	7.75	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	5.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	6.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	6.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	7.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 650
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .119731514
CHARACTERISTIC LENGTH (1/LAMBDA) = 8.35202002
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	1.97	2.61	3.52	4.61	6.00	8.03	0.00	0.00
6.0	-1.00	2.34	3.25	4.34	5.81	7.93	0.00	0.00	0.00
7.0	-1.00	2.70	3.79	5.26	7.19	0.00	0.00	0.00	0.00
8.0	-1.00	3.15	4.43	6.18	0.00	0.00	0.00	0.00	0.00
9.0	-1.00	3.61	5.08	7.37	0.00	0.00	0.00	0.00	0.00
10.0	-1.00	4.07	5.81	0.00	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	4.52	6.73	0.00	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	4.98	7.66	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	5.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	6.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	6.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	7.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	8.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 750
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .115523808
CHARACTERISTIC LENGTH (1/LAMBDA) = 8.65622434
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	2.25	3.06	4.07	5.44	7.19	0.00	0.00	0.00
6.0	-1.00	2.70	3.70	5.08	6.92	0.00	0.00	0.00	0.00
7.0	-1.00	3.15	4.43	6.18	0.00	0.00	0.00	0.00	0.00
8.0	-1.00	3.61	5.26	7.46	0.00	0.00	0.00	0.00	0.00
9.0	-1.00	4.16	6.09	0.00	0.00	0.00	0.00	0.00	0.00
10.0	-1.00	4.70	7.01	0.00	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	5.26	8.13	0.00	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	5.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	6.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	7.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	8.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 800
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .113674831
CHARACTERISTIC LENGTH (1/LAMBDA) = 8.79702212
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	2.34	3.25	4.43	5.91	7.93	0.00	0.00	0.00
6.0	-1.00	2.88	3.97	5.44	7.56	0.00	0.00	0.00	0.00
7.0	-1.00	3.34	4.79	6.73	0.00	0.00	0.00	0.00	0.00
8.0	-1.00	3.88	5.62	8.23	0.00	0.00	0.00	0.00	0.00
9.0	-1.00	4.43	6.54	0.00	0.00	0.00	0.00	0.00	0.00
10.0	-1.00	5.08	7.66	0.00	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	5.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	6.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	7.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	8.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 850
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .111964948
CHARACTERISTIC LENGTH (1/LAMBDA) = 8.93136665
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	-1.00	2.52	3.52	4.70	6.27	8.62	0.00	0.00	0.00
6.0	-1.00	3.06	4.25	5.91	8.23	0.00	0.00	0.00	0.00
7.0	-1.00	3.61	5.08	7.28	0.00	0.00	0.00	0.00	0.00
8.0	-1.00	4.16	6.00	0.00	0.00	0.00	0.00	0.00	0.00
9.0	-1.00	4.79	7.10	0.00	0.00	0.00	0.00	0.00	0.00
10.0	-1.00	5.44	8.33	0.00	0.00	0.00	0.00	0.00	0.00
11.0	-1.00	6.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.0	-1.00	6.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.0	-1.00	7.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	-1.00	8.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 900
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .11037639
CHARACTERISTIC LENGTH (1/LAMBDA) = 9.05990857
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	1.87	2.70	3.70	4.98	6.73	0.00	0.00	0.00	0.00
6.0	2.25	3.25	4.52	6.27	8.92	0.00	0.00	0.00	0.00
7.0	2.61	3.79	5.44	7.84	0.00	0.00	0.00	0.00	0.00
8.0	2.97	4.43	6.45	0.00	0.00	0.00	0.00	0.00	0.00
9.0	3.34	5.08	7.66	0.00	0.00	0.00	0.00	0.00	0.00
10.0	3.79	5.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.0	4.25	6.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.0	4.70	7.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.0	5.08	8.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	5.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	6.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	6.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	7.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 950
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .108894492
CHARACTERISTIC LENGTH (1/LAMBDA) = 9.18320097
AST WEIGHT = 11000

	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	1.97	2.79	3.97	5.35	7.28	0.00	0.00	0.00	0.00
6.0	2.34	3.43	4.79	6.73	0.00	0.00	0.00	0.00	0.00
7.0	2.70	4.07	5.81	8.42	0.00	0.00	0.00	0.00	0.00
8.0	3.15	4.70	6.92	0.00	0.00	0.00	0.00	0.00	0.00
9.0	3.61	5.44	8.23	0.00	0.00	0.00	0.00	0.00	0.00
10.0	4.07	6.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.0	4.43	7.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.0	4.98	7.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.0	5.44	9.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	6.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	7.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	7.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

INPUT DATA:
SIGMA MAX = 1000
ICE THICKNESS FROM .5 M TO 1.3 M
ICE BEAM FROM 5 M TO 17 M WIDE.
LAMBDA = .107507017
CHARACTERISTIC LENGTH (1/LAMBDA) = 9.30171839
AST WEIGHT = 11000

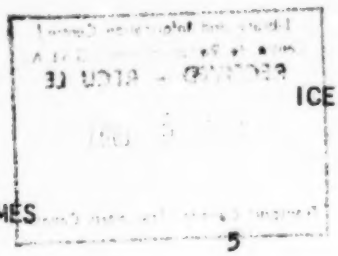
	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
5.0	2.07	2.97	4.16	5.62	7.75	0.00	0.00	0.00	0.00
6.0	2.43	3.61	5.08	7.19	0.00	0.00	0.00	0.00	0.00
7.0	2.88	4.25	6.18	9.12	0.00	0.00	0.00	0.00	0.00
8.0	3.34	4.98	7.37	0.00	0.00	0.00	0.00	0.00	0.00
9.0	3.79	5.71	8.82	0.00	0.00	0.00	0.00	0.00	0.00
10.0	4.25	6.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.0	4.70	7.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.0	5.26	8.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.0	5.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.0	6.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0	6.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0	7.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0	8.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ARCTEC CANADA LIMITED

APPENDIX E

ICE THICKNESS OBSERVATIONS

ARCTEC CANADA LIMITED



ICE THICKNESS CHANGES

PLOTS NAMES	DAYS 5	17	19	22	TOTAL CHANGE
			THICKNESS (cm)		
PLOWD	83.2	81.7	82	80.8	-2.4
SNOWD	81.7	85	82.3	82.9	1.2
SCARD	79.6	81.7	78.6	79.6	0
DUSTD	88.1	86.3	84.1	85.3	-2.8
CONTD	82.6	83.8	87.2	83.2	0.6
1ST SCAR	81.7	83.5	80.2	79.6	-2.1
2ND SCAR	77.4	79.6	77.4	79.3	1.9
PL1 SCAR	84.1	84.7	80.8	79.3	-4.8
SN1 SCAR	78.9	82.3	79.3	80.2	1.3
PL2 SCAR	80.2	79.3	77.7	80.2	0
SN2 SCAR	75	80.2	77.1	78.6	3.6
PL CTRL	86.9	80.8	89.3	79.3	-7.6
SN CTRL	78	86.9	85.3	86.9	8.9
PLDUST	82.3	81.7	80.8	84.7	2.4
SNDUST	94.2	90.8	87.8	86.3	-7.9